UDC 796.012

KINESIOLOGY

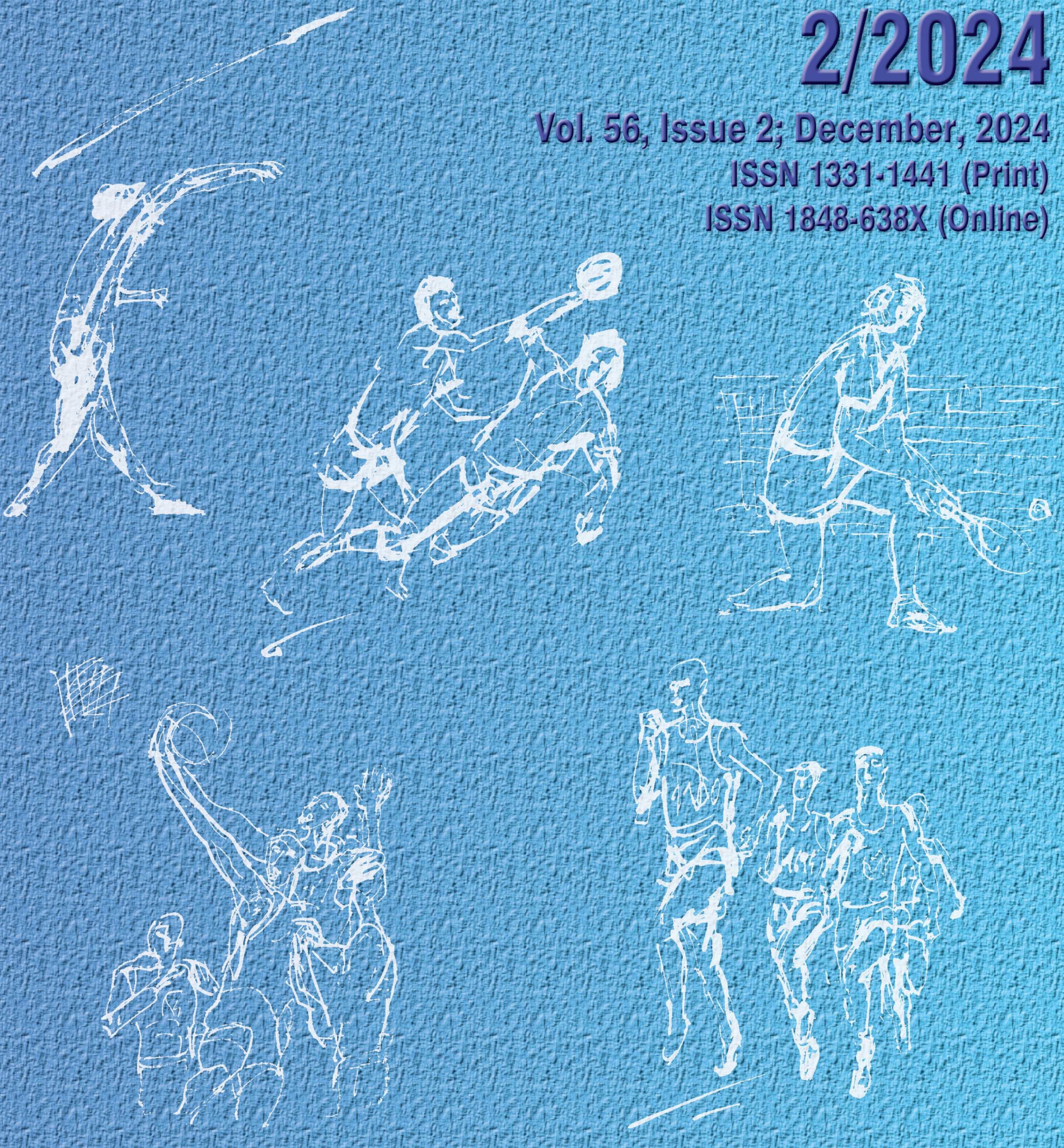
International Journal of Fundamental and Applied Kinesiology

2/2024

Vol. 56, Issue 2; December, 2024

ISSN 1331-1441 (Print)

ISSN 1848-638X (Online)



KINESIOLOGY

International Journal of Fundamental and Applied Kinesiology

PUBLISHED BY FACULTY OF KINESIOLOGY UNIVERSITY OF ZAGREB, CROATIA

Indexed in:

Web of Science Core Collection: Science Citation Index Expanded, Social Sciences Citation Index

Scopus

EBSCO: SPORT Discus with Full Text, Academic Search Complete

Index Copernicus International (ICI)

2023/2024. Impact Factor (Journal Citation Report)

- Impact Factor: 0.9
- Journal Citation Indicators (JCI): 0.47
- Scimago Journal Rank (SJR): 0.405.
- Impact Score: 1.20.
- Quartile: Q2
- H-index: 31

Editorial Office **KINESIOLOGY**
Faculty of Kinesiology
Horvaćanski zavoj 15, 10000 Zagreb, CROATIA
Tel: +385 1 3658 622; 3658 640
fax: +385 1 3634 146
e-mail: kinesiology.office@kif.hr
URL: http:/www.kif.hr

Kinesiology – (ISSN Print 1331-1441) ISSN 1848-638X (Online) is an international journal published twice a year. Publishing of the Journal is granted by the Ministry of Science and Education of the Republic of Croatia.

Full-text available free of charge at http://hrcak.srce.hr/kineziologija

UDC 796.012

(ISSN 1331-1441 Print)
ISSN 1848-638X (Online)

K I N E S I O L O G Y

International Journal of Fundamental and Applied Kinesiology

Vol. 56(2024) No.2 (187-358)

Contents

Full-text available free of charge at http://hrcak.srce.hr/kineziologija

THE EFFECTS OF A SCHOOL BAG LOAD CARRIAGE ON GAIT KINEMATICS IN CHILDREN: A SCHOOL-BASED STUDY

Kateřina Jenčíková[1], Mario Kasović[1,2], and Martin Zvonař[1,3]

[1]*Department of Physical Activities and Health Sciences, Faculty of Sport Studies, Masaryk University, Brno, Czech Republic*

[2]*University of Zagreb Faculty of Kinesiology, Department of General and Applied Kinesiology, Zagreb, Croatia*

[3]*Department of Physical Education and Sport, Faculty of Education, Catholic University in Ružomberok, Ružomberok, Slovakia*

Original scientific paper
DOI 10.26582/k.56.2.1

Abstract:

The main purpose of this study was to explore the impact of carrying a school bag on spatiotemporal gait parameters in a sample of primary school children. Two-hundred and twenty-one children (124 girls and 97 boys), aged 9.5±2.1 years, were randomly selected from three primary schools in the city of Brno, Czech Republic. Gait analysis without and with the school bag load carriage was performed using the Zebris pressure platform. The software generated the data for spatial (foot rotation, step length, stride length and step width) and temporal (step time, stride time, cadence and gait speed) gait parameters. The mean school bag weight was 4.86±1.21 kg. Repeated measures ANCOVA adjusted for sex and age showed that carrying a school bag resulted in a higher external left foot ($F_{1,220}$=8.390, p<.001) and right foot ($F_{1,220}$=8.791, p<.001) rotation, narrow step width ($F_{1,220}$=6.113, p<.001), longer left foot ($F_{1,220}$=5.556, p=.011) and right foot ($F_{1,220}$=4.508, p=.021) step time, longer stride time ($F_{1,220}$=3.773, p=.035), less cadence ($F_{1,220}$=3.773, p=0.038) and slower gait speed ($F_{1,220}$=4.131, p=.029). Carrying a school bag weight may change gait characteristics in school-going children, especially in temporal parameters.

Keywords: *walking, primary school students, backpack, equipment*

Introduction

At the beginning of compulsory schooling, a few significant changes start to impact the daily child's routine, especially a non-negligible load on the musculoskeletal system caused by carrying school bags (Chaudhari, Saini, Bharti, Gopinathan, & Narang, 2021; Dockrell, Simms, & Blake, 2015a).

As walking is one of the main biological tasks for humans, constant heavy loads combined with overweight and obesity may lead to pain or discomfort in the lower limbs (Hills, Hills, Hennig, McDonald, & Bar-Or, 2001). Carrying heavy school bags is also associated with a multitude of bodily distresses and health problems such as musculoskeletal discomfort, posture imbalance, and back or shoulder pain (Bika-Lélé, et al., 2020; Delele, Janakiraman, Bekele Abebe, Tafese, & van de Water, 2018; Dockrell, et al., 2015a; Catan, et al., 2020; Kasović, Gomaz, & Zvonar, 2019). At school age, children's musculoskeletal systems are still developing and are negatively influenced by many factors, such as inappropriate sitting positions and lack of physical activity (Negrini & Carabalona, 2002; Siambanes, Martinez, Butler, & Haider, 2004).

School-going children load their school bags with books, workbooks, school supplies, gym items, slippers, water bottles, etc. Carrying an excessive load is a health problem for children of both sexes (Kasović, et al., 2019), including musculoskeletal pain, discomfort and fatigue (Bika-Lélé, et al., 2020; Catan, et al., 2020; Delele, et al., 2018; Dockrell, Blake, & Simms, 2015b; Kasović, Štefan, & Zvonar, 2019a), but it must be remembered that school bags have more health risk factors than just the weight (Kasović, Zvonar, Gomaz, Bolčević, & Anton, 2018). Other important factors of school bags concerning children's health are its size, duration and method of carrying it, (in)correct placement on the back, and elasticity of the straps (Huang, Sui, & He, 2020; Kasović, et al., 2018). Abnormal gait in relation to heavy load generally results in impaired muscle strength, increased or decreased range of motion of lower extremities and increased energy expenditure, which leads to a higher incidence of injury, pain and discomfort, especially in the lower back, hip, knee and ankle regions of the body (Bika-Lélé, et al., 2020; Catan, et al., 2020; Delele, et al., 2018; Dockrell, et al., 2015a; Kasović, et al., 2019; Siambanes, et al., 2004).

As heavy school bags have become a widespread problem, many studies have been conducted to determine the safe backload limit to carry for school-going children. School bags are in most cases identified as overweight (Kasović, et al., 2019a; Khallaf, 2016) with regard to the ratio between the total body weight of the child and the weight of his/her backpack. Many researchers agree with the statement that the school bag should not exceed 10% of the child's total body weight (Catan, et al., 2020; Song, Yu, Zhang, Sun, & Mao, 2014). Guidelines for recommended loads are mostly within 10-15% of the child's total body weight (Kasović, et al., 2018), although global recommendations have not yet been established (Dockrell, et al., 2015a).

In recent decades, the concern about heavy school bags has been growing among health practitioners, parents, and educators to reduce the weight of school bags that may cause serious effects on children's gait (Chow, et al., 2005; Gupta, Kalra, & Iqbal, 2016). The foot is considered as an essential part of the body (Scott, Menz, & Newcombe, 2007). Furthermore, it absorbs various shocks over irregular surfaces and maintains forward propulsion (Kasović, Štefan, Borovec, Zvonař, & Cacek, 2020).

An individual's gait gradually changes from an early age, and studies do not coincide with at what age children achieve adult-like gait patterns. However, research indicates that it is at the age between 5-7 years (Kasović, et al., 2020). Several studies have investigated the relationship between school bag weight and health-related issues, including back (Bika-Lélé, et al., 2020; Negrini & Carabalona, 2002) and musculoskeletal pain (Chen & Mu, 2018; Delele, et al., 2018; Dockrell, et al., 2015b; Khallaf, 2016).

Most previous research aiming to establish the effects of carrying excessive weight on gait kinematics and kinetics have been conducted among military personnel (Attwells, Birrell, Hooper, & Mansfield, 2006; Birrell & Haslam, 2010; Singh & Koh, 2009). In general, heavier loads lead to small-to-moderate changes in kinematic and moderate-to-high changes in kinetic parameters. Although carrying heavy loads in children represents a public health problem, to date little evidence has been provided regarding gait changes under different loading conditions.

In recent years, attention has been devoted to considering the connections between carrying school bags and changes in spatiotemporal and kinetic gait parameters (Ahmad & Barbosa, 2019; Kasović et al., 2018). In a study by Ahmad and Barbosa (2019), findings showed that heavier school bag loads were associated with the most common parameters used to describe gait kinematics, i.e., slower gait velocity and longer duration of the stance, swing and double support phases, and a smaller number of steps per minute, while no changes in the stride length were observed. In the same study, the authors found significant increases in the contact area, contact time, pressure-time and force-time integrals, and mean plantar pressure, when heavier school bag loads were added, especially beneath the toe and midfoot regions of the foot (Ahmad & Barbosa, 2019). A study by Kasović et al. (2018) showed that walking with a school bag changes the plantar pressure patterns in children when compared to walking without an external load, which was also confirmed by previous evidence (Connolly, et al., 2008; Hong, Li, Wong, & Robinson, 2000a; Pau, et al., 2015).

Combining heavy external forces with changes in gait kinematics has been shown to highly impact locomotor apparatus in children (Ahmad & Barbosa, 2019). Based on the aforementioned studies, the findings on the effects of carrying loads and gait changes in school-going children seem to be inconclusive. By defining potential effects, public health policies may be able to recommend an appropriate school bag mass and school supply positioning within the school bag, in order to lower potential stress-related injuries and changes in locomotor patterns. Another problem lies in the fact that the relative load carried by school-going children has been considered in previous studies as one of the contributory factors to developing musculoskeletal problems among this age group (Bika-Lélé, et al., 2020; Delele, et al., 2018; Dockrell, et al., 2015a), including changes in head/neck positioning and deviations in spinal posture and trunk muscle activity levels, which all affect gait patterns. Since children go through rapid musculoskeletal and physical development, carrying heavy school bags has drawn public health concerns raised by parents, educators and health-related professionals. Although there have been studies controlling for age and sex in the literature, they do not deal with the issue of carrying school bags (McKay, et al., 2017).

Therefore, the main purpose of this study was to explore the effects of carrying a school bag on spatiotemporal and kinematic gait parameters in a sample of primary school children (6-14 years of age). As part of this, several sex and age-specific kinematic foot variables in primary school children were established. According to the aforementioned, we hypothesized that gait characteristics under the 'school bag load' would significantly change, compared to the 'no load' condition.

Methods

Study participants

For the purpose of this cross-sectional study, we randomly approached to five elementary schools in the city of Brno, Moravska region, Czech Republic. A total of 452 requests for participation, containing a detailed description of the purposes of the study and the experimental protocol, were delivered to all the pupils enrolled in three primary schools in Brno (Czech Republic). Of these, 221 families expressed formal acceptance by signing an informed consent form and 221 children (124 girls and 97 boys), aged 9.5±2.1 years, from the Czech Republic were included in this study. To compute the sample size with G*power software (Kang, 2021), to assume a medium effect (f=0.25), 5.0% error probability and 80.0% statistical power with two measurements ('no load' vs. 'school bag load'), two covariates (sex and age), and correlation between the two measurements of 0.5, these outputs yielded a sample size of at least 211 participants. Inclusion criteria were the following: (i) participants (boys and girls) must carry a school bag on a daily basis (on their back); (ii) participants aged between 6-14 years; (iii) no clinical diagnosis of musculoskeletal or neurological diseases. Individuals diagnosed with acute or chronic conditions that prevented them from attending physical education classes as well as individuals lacking complete data, were excluded.

Conforming with the General Data Protection Regulation (GDPR), all the procedures were anonymous and in accordance with the Declaration of Helsinki, where all participants were marked in the software under a unique code. This study was approved by the Ethical Committee of the Faculty of Sports Studies, Czech Republic (Ethical code number: 0560/2018).

Gait analysis

Zebris FDM (Force Distribution Measurement) plantar pressure platform was used to assess the spatiotemporal gait parameters (FDM; GmbH, Munich, Germany; number of sensors: 11,264; sampling rate: 100 Hz; sensor area: 149 cm×54.2 cm; Figure 1) (Internet page: https://www.zebris.de/fileadmin/Editoren/zebris-PDF-Manuals/Medizin/Software/Alte_ Versionen/ Manua 1_zebris_ FDM_1.16.x_R1_EN_web.pdf). Each participant was instructed to walk barefoot at a comfortable and natural speed across the platform, looking straight forward and without targeting the platform. After completing the first trial and reaching the end of the walkway, the participant needed to turn 180° around and continue to walk again over the platform. The protocol was repeated for six trials, where at least two footprints on the platform were always recorded, as recommended by previous evidence (Kasović, et al., 2020). It has been suggested that barefoot gait analysis is sufficient for clinical studies and is safe and sensitive for the platform (Van Alsenoy, et al., 2019).

The following variables were generated by the FDM software for this study: foot rotation (°)_left and right foot; step length (cm)_left and right foot (the distance from the heel of one foot to the heel of the other foot); stride length (cm; the distance from the heel of the left foot to the heel of the next left foot), step width (cm; the distance between the feet), step time (s)_left and right foot (the time from the contact of one heel of the foot to the heel of the other foot); stride time (s; the time from the contact of the left heel to the heel of the next left foot), cadence (steps/min) and gait speed (km/h). For accuracy, foot rotation (°) describes the angle between the longitudinal axis of the foot and the walking/running direction whereby a negative value characterizes inward rotation and a positive value characterizes outward rotation (Van Alsenoy, et al., 2019). Of note, the internal consistency between the trials was >0.90 for all the study variables and both conditions, while previous studies have shown that Zebris FDM platform has acceptable test-retest reliability and validity properties (Van Alsenoy, et al., 2019). This study was conducted at the end of the year 2020 when participants were measured on a random school day (Monday-Friday) in their schools during physical education classes in the morning hours between 9:00-11:00 a.m. During the testing, children wore light clothes (a T-shirt with shorts and socks, which were removed when walking over the platform). The school bags (4.86 kg ± 1.21) in all cases were worn over two shoulders. Relative schoolbag weight was calculated by the following formula:

(school bag weight/child weight)*100.

Procedure

The participants started barefoot walking 4.5 meters ahead of the pressure platform and finished the trial 4.5 meters after the end of the platform to preserve acceleration and deceleration in gait. After completing the first task, the same task was repeated while carrying the school bag. Gait assessments were measured at the participant's school. Before the measurement itself, each participant crossed the platform several times to avoid misunderstandings about treads and speed. Additionally, all participants were required to look straight ahead without targeting the pressure platform. The measurement protocol was done with randomization, where participants were not familiar with the order of testing nor with the testing condition ('no load' vs. 'schoolbag load'). The testing procedure lasted from September to December 2020.

Data analysis

The basic descriptive statistics are presented as mean ± standard deviation (SD). The Kolmogorov-Smirnov test was calculated for all experimental data before inferential testing. The assumptions of normality and sphericity to run the analyses were met. Repeated measures ANCOVA with one factor (sex), one covariate (age) and two conditions (no load and school bag load) was used to calculate the differences. Finally, the effect size (ES) ranges from small (<0.3), through medium (0.3-0.5) and strong (0.5-0.8) to very strong (>0.80), determined by Cohen's d (1988). The significance was set at p≤.05. The measured data were transformed directly from Zebris software into a raw data format. All analyses were performed in Statistical Packages for Social Sciences, version 22 (IBM, Chicago, IL, USA).

Results

Basic descriptive statistics of the study participants are presented in Table 1. Boys were taller, heavier and carried heavier school bags (kg) compared to girls.

Figure 1 shows the mean and SD differences in spatial gait parameters between the two conditions: 1) 'no load' vs. 2) 'school bag load'. When carrying the school bag load, significant main effects for the following spatial parameters were found: increases in left foot (89.6%, $F_{1,220}$=8.39, ES=0.30, p<.001) and right foot (74.1%, $F_{1,220}$=8.79, ES=0.27, p<.001)

Table 1. Basic descriptive statistics of the study participants (N=221)

Basic study variables	Total (N=221)	Boys (n=97)	Girls (n=124)	*p* for Gender
	mean ± SD	mean ± SD	mean ± SD	
Age (years)	9.5 ± 2.1	9.7 ± 2.1	9.3 ± 2.0	0.105
Height (cm)	140.3 ± 13.3	142.4 ± 13.5	138.6 ± 13,0	0.082
Weight (kg)	35.5 ± 12.07	37.14 ± 11.9	34.3 ± 12.1	0.062
Body mass index (kg/m²)	14.4 ± 3.1	18.3 ± 2.9	17.9 ± 3.2	0.041
Weight of a school bag (kg)	4.86 ± 1.21	5.04 ± 1.25	4.7 ± 1.2	0.038
Relative school bag weight (%)	14.5 ± 3.8	14.2 ± 3.5	14.7 ± 4.0	0.317

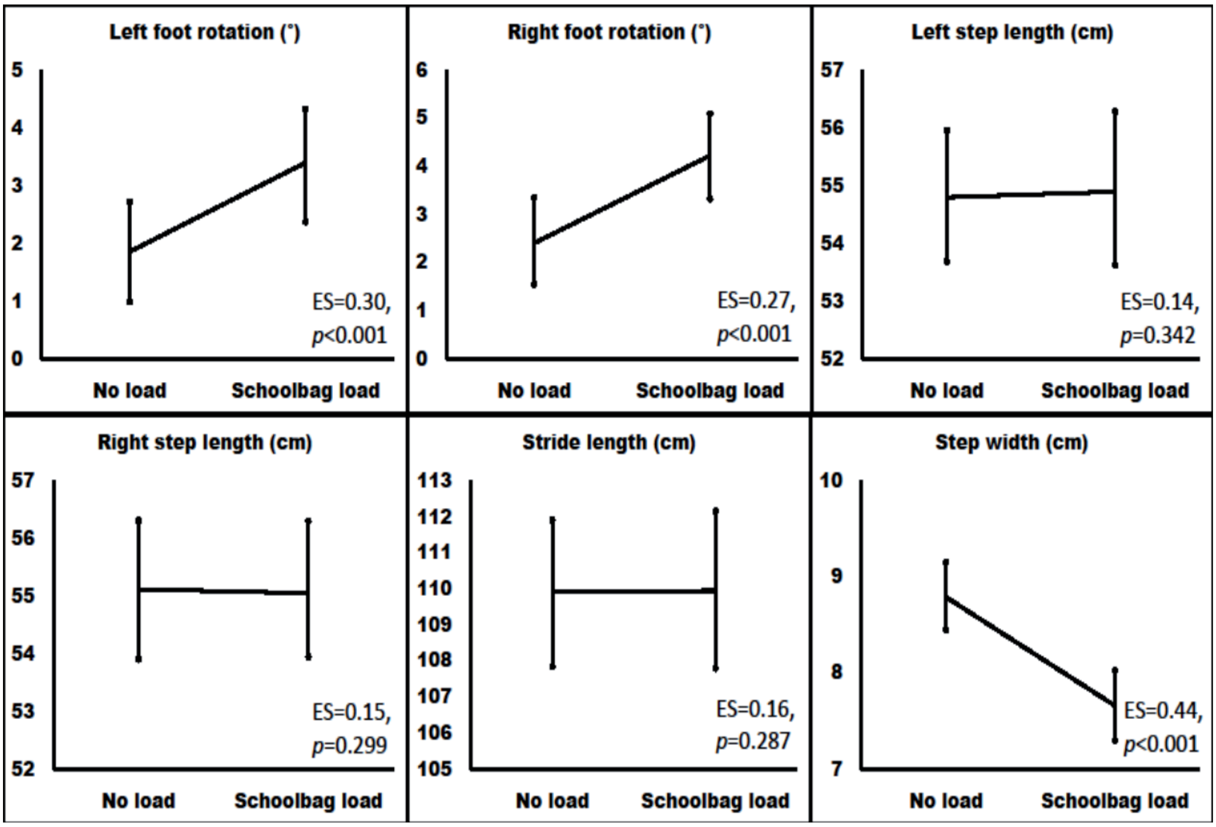


Figure 1. Differences in spatial gait parameters between two conditions: 1) 'no load' vs. 2) 'school-bag load' of the study participants (N=221).

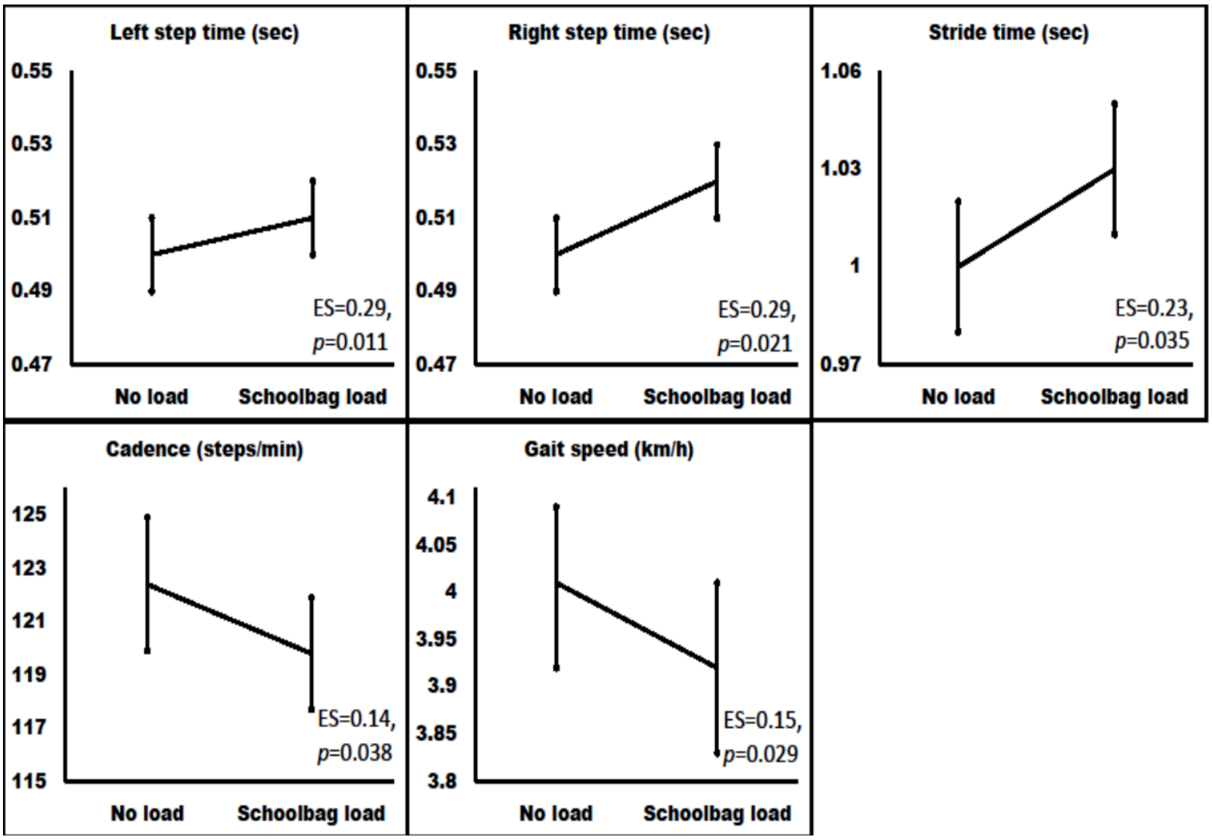


Figure 2. Differences in temporal gait parameters between two conditions: 1) 'no load' vs. 2) 'school-bag load' of the study participants (N=221).

rotations, and a decrease in step width (12.9%, $F_{1,220}$=6.11, ES=0.44, p<.001) were observed. No significant changes in other spatial gait parameters were observed (p<.05).

Changes in temporal gait parameters under the school bag weight are presented in Figure 2. When carrying a school bag load, significant main effects for the following temporal parameters were found: increases in left foot (4.0%, $F_{1,220}$=5.57, ES=0.29, p=.011) and right foot (4.0%, $F_{1,220}$=4.51, ES=0.29, p=.021) step time and stride time (3.0%, $F_{1,220}$=3.81, ES=0.23, p=.035) as well as decreases in cadence (1.8%, $F_{1,220}$=3.77, ES=0.14, p=.038) and gait speed (2.2%, $F_{1,220}$=4.13, ES=0.15, p=.029). When sex and age were put separately and simultaneously into the model, no significant interactions between time, sex and age were observed.

Discussion and conclusions

The main purpose of this study was to explore the effects of carrying a school bag load on spatio-temporal gait kinematic parameters in a sample of primary school children. The main findings of this study are: (1) carrying a school bag load increases external left and right foot rotation, left and right step time and stride time, while it decreases step width, cadence and gait speed; 2) the significant effects are only observed for time, while time*sex and time*age interactions remained non-significant.

Since this is the first sex- and age-specific study examining spatiotemporal gait parameters in primary school-aged children, it is somewhat difficult to compare the results with previous literature. Most of previous studies have focused on biomechanical foot parameter changes while walking with school bags (Connolly, et al., 2008; Hong &Brueggemann 2000b; Kasović, et al, 2018; Pau, et al., 2015)**;** however, these have been mostly based on the changes in plantar pressure distribution. Connected with the field of gait kinematics, there were no significant differences nor time effects in spatial and temporal gait kinematics when walking without and with school bags under two conditions (elastic and non-elastic straps) (Huang, et al., 2020). Ahmad and Barbosa (2019) conducted the measurement on a relatively small sample size (N=57) and suggested that gait kinematics in children was affected by carrying gradually heavier loads in school bags. Specifically, heavier school bag loads led to lower cadence and slower gait speed, compared to the 'no load' condition. Indeed, significant and moderate main effects of the heavier load on slower gait speed, lower cadence, and longer durations of the stance, swing and double support phases were shown, while no significant main effects on the stride length were observed (Ahmad & Barbosa, 2019).

Although we found significant changes in some spatial and temporal parameters, the lack of change in other gait parameters with increasing load points to hypothetical adaptations at physiological and kinetic responses. Evidence suggests that increasing loads lead to cardiovascular, respiratory and electromyography adaptations (Al-Khabbaz, Shimada, & Hasegawa, 2008; Li, Hong, & Robinson, 2003). Similar findings have been observed previously (Ahmad & Barbosa, 2019; Connolly, et al., 2008; Hong, et al., 2000; Pau, et al., 2015). It should be noted that the ES values obtained in this study between the two conditions were only trivial to small, which coincides with what was reported previously (Ahmad & Barbosa, 2019; Hong, et al., 2000a; Pau, et al., 2015). The lack of larger effects in the spatiotemporal gait parameters may be explained by children's physiological and kinetic adaptations (Ahmad & Barbosa, 2019). For example, it has been suggested that energy expenditure increases with heavier loads, especially from 15.0% of body weight onwards (Hong, et al., 2000a). A load change in our study (14.5% of total body weight) resulted in significant changes, which could be also explained by children adapting to a new set of higher motor control constraints (Ahmad & Barbosa, 2019). A study by Chow et al. (2005) exhibited similar results, where gait speed and cadence decreased significantly with increasing school bag load, while double support time increased. However, there is still no clear consensus on the maximum load to be carried by children in order to prevent changes in spinal posture, thoracic kyphosis, ground reaction forces, physical discomfort and muscle activity.

Although some studies recommend a load of 10% of the child's body weight (Perrone, Orr, Hing, Milne, & Pope, 2018) to be the top-ceiling point, we were unable to determine how small difference between 'no load' vs. 'a school bag load' would be enough to affect children's health. However, trivial to small ES obtained in our study might be the first step in determining recommendations for a relative school bag weight in school-going children. Since both spatiotemporal and kinetic gait parameters change under loading conditions of 10 to 20% (Perrone, et al., 2018), future research should be able to define optimal cut-off points of relative school bag weight and minimal clinically important differences influencing negative biomechanical gait changes. Also, we observed non-significant main effects for time*sex and time*age interactions, which may be explained by a relatively small sample size, different sex/age ratio within group and not controlling for other physiological (maturity status, body composition) or environmental factors (school bag characteristics). Due to these shortcomings, we were unable to further examine the nature of non-significant interactions; however, the findings suggest that sex and age did not have a significant role in affecting the magnitude of change between 'no load' vs. 'school bag load' in primary school-aged children.

Future research

It has been well-documented that load carriage may change gait patterns (Ahmad & Barbosa, 2019; Chow, et al., 2005; Kasović, et al., 2020) contributing to negative health-related outcomes, like musculoskeletal pain and discomfort (Bika-Lélé et al., 2020; Chaudhari, et al., 2021; Delele, et al., 2018; Dockrell, et al., 2015c). Indeed, heavy loads carried by children at early age may contribute to larger stress fractures in lower limbs and spine, causing stiffness and pain, especially in the lower back. Moreover, excessive school bag load can in long-term result in deteriorating biomechanical gait patterns (Delele, et al., 2018; Dockrell, et al., 2015a). Thus, school bag-loaded walking and running in daily life may indirectly increase the risk of lower extremity injuries, indicating that school bags may increase gait instability and posture compensations, which may lead to injuries and pain, especially in the lower back and lower extremities (Wang, et al., 2023).

Along with biomechanical and structural changes, carrying heavy loads has been shown to impact cardiorespiratory system by increasing energy expenditure and fatigue (Hong, et al., 2000a). On the other hand, a recent systematic review by Yamato, Maher, Traeger, Wiliams, & Kamper (2018) has shown that school bag characteristics such as weight, design and carriage method do not increase the risk of developing back pain in children and adolescents. Therefore, future research should explore other potential mechanisms which connect an external load with gait characteristics changes and pain.

Limitations of the study

This study is not without limitations. First, to give the possibility to assess natural changes in individual growth as our participants were children, a longitudinal study should have been conducted. By using a longitudinal design, we would have been able to examine causal differences and possible follow-up effects of school bag loads on spatiotemporal foot parameters. Since previous studies have shown that walking with an unusual amount of load may lead to musculoskeletal injuries (Chaudhari, et al., 2021; Hills, et al., 2001), future research should explore longitudinal associations between school bag loads and the incidence of lower- and upper-body injury risks. Second, the real school bag of each child was used for the measurement to obtain the % of total school bag weight of the child. Our calculations do not apply to the specific weight for a particular person, correct placement on the back or the control of proper size of the bag; therefore, our results are relative to the mean school bag weight which was 14.5%. Also, the measurement was one-off (which allowed a larger number of participants), so it could be to some extent influenced by the current state of each child (e.g., his/her mood state). Suitable improvement for more optimal results would be to measure the children repeatedly. Indeed, a deeper insight into gait changes could be gathered by using motion-capture systems with 3-D analyses and muscle activity movements in frontal, sagittal and transversal planes. Although previous studies have confirmed the reliability and validity properties of the Zebris platform, this study lacked test-retest and correlating analyses with other motion systems. Next, the load of the school bag was the target of the study and future research should take care of including the condition of the 'empty school bag' to help eliminate the effect of the school bag itself. We were unable to compare values of biomechanical foot parameters with other normative data in children since such data are yet to be established. Finally, the nature of doing sports and being sedentary or physically active might have led to different adaptations of carrying school bags, which was not controlled for.

This is the first sex- and age-specific spatiotemporal gait kinematics study in children. The main purpose of this study was to explore the effects of carrying school bags on spatiotemporal gait parameters in a sample of primary school children. We found significant changes in several spatiotemporal gait parameters under loading conditions, pointing out that school-going children underwent significant changes in gait biomechanics while carrying school bag loads. From a public health perspective, the findings of this study should help health-related professionals and professionals who are part of the school bag ergonomics and design industry. Although the relative school bag weight was within the limits of 10 to 15 %, the position of school bag supplies and weight within the school bag should be of important interest. Also, by examining locomotor posture in annual systematic check-ups by pediatricians and physical functioning by physical education teachers, public health experts could have comparable datasets within and between the countries that may help to establish future directions and recommendations regarding the nature of school bag weight.

References

Ahmad, H.N., & Barbosa, T.M. (2019). The effects of backpack carriage on gait kinematics and kinetics of schoolchildren. *Scientific Reports*, *9*(1), 3364. https://doi.org/10.1038/s41598-019-40076-w

Al-Khabbaz, Y.S., Shimada, T., & Hasegawa, M. (2008). The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. *Gait and Posture*, *28*(2), 297-302. https://doi.org/10.1016/j.gaitpost.2008.01.002

Attwells, R.L., Birrell, S.A., Hooper, R.H., & Mansfield, N.J. (2006). Influence of carrying heavy loads on soldiers' posture, movements and gait. *Ergonomics*, *49*(14), 1527-1537. https://doi.org/10.1080/00140130600757237

Bika-Lélé, C.B., Mbang-Bian, W., Djuine-Soh, E.L., Ondoa, J.B., Mandengue, S.H., & Temfemo A. (2020). Effect of schoolbag weight on musculoskeletal pain among primary school children in Yaounde, Cameroon: A cross-sectional study. *International Journal of Medical Studies*, *8*, 96-101.

Birrell, S.A., & Haslam, R.A. (2010). The effect of load distribution within military load carriage systems on the kinetics of human gait. *Applied Ergonomics*, *41*(4), 585-590. https://doi.org/10.1016/j.apergo.2009.12.004

Catan, L., Amaricai, E., Onofrei, R.R., Popoiu, C.M., Iacob, E.R., Stanciulescu, C.M., Cerbu, S., Horhat, D.I., & Suciu, O. (2020). The impact of overweight and obesity on plantar pressure in children and adolescents: A systematic review. *International Journal of Environmental Research and Public Health*, *17*(18), 6600. https://doi.org/10.3390/ijerph17186600

Chaudhari, M., Saini, S.K., Bharti, B., Gopinathan, N.R., & Narang, K. (2021). Heavy school bags and musculoskeletal system problems among school-going children. *Indian Journal of Pediatrics*, *88*(9), 928. https://doi.org/10.1007/s12098-021-03807-4

Chen, Y.L., & Mu, Y C. (2018). Effects of backpack load and position on body strains in male schoolchildren while walking. *PloS One*, *13*(3), e0193648. https://doi.org/10.1371/journal.pone.0193648

Chow, D.H., Kwok, M.L., Au-Yang, A.C., Holmes, A.D., Cheng, J.C., Yao, F.Y., & Wong, M.S. (2005). The effect of backpack load on the gait of normal adolescent girls. *Ergonomics*, *48*(6), 642-656. https://doi.org/10.1080/00140130500070921

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Academic Press.

Connolly, B.H., Cook, B., Hunter, S., Laughter, M., Mills, A., Nordtvedt, N., & Bush, A. (2008). Effects of backpack carriage on gait parameters in children. *Pediatric Physical Therapy*, *20*(4), 347-355. https://doi.org/10.1097/PEP.0b013e31818a0f8f

Delele, M., Janakiraman, B., Bekele Abebe, A., Tafese, A., & van de Water, A.T.M. (2018). Musculoskeletal pain and associated factors among Ethiopian elementary school children. *BMC Musculoskeletal Disorders*, *19*(1), 276. https://doi.org/10.1186/s12891-018-2192-6

Dockrell, S., Simms, C., & Blake, C. (2015a). Guidelines on schoolbag use: Messaging to inform the stakeholders. Work (Reading, Mass.), 54(2), 489-492. https://doi.org/10.3233/WOR-162344

Dockrell, S., Blake, C., & Simms, C. (2015b). Guidelines for schoolbag carriage: An appraisal of safe load limits for schoolbag weight and duration of carriage. *Work (Reading, Mass.)*, *53*(3), 679-688. https://doi.org/10.3233/WOR-162260

Dockrell, S., Simms, C., & Blake, C. (2015c). Schoolbag carriage and schoolbag-related musculoskeletal discomfort among primary school children. *Applied Ergonomics*, *51*, 281-290. https://doi.org/10.1016/j.apergo.2015.05.009

Gupta, I., Kalra, P., & Iqbal, R. (2016). Gait parameters in school going children using a markerless approach. *Current Science*, *11*, 1668.

Hills, A.P., Hennig, E.M., McDonald, M., & Bar-Or, O. (2001). Plantar pressure differences between obese and non-obese adults: A biomechanical analysis. *International Journal of Obesity and Related Metabolic Disorders*, *25*(11), 1674-1679. https://doi.org/10.1038/sj.ijo.0801785

Hong, Y., Li, J.X., Wong, A.S., & Robinson, P.D. (2000a). Effects of load carriage on heart rate, blood pressure and energy expenditure in children. *Ergonomics*, *43*(6), 717-727. https://doi.org/10.1080/001401300404698

Hong, Y., & Brueggemann, G.P. (2000b). Changes in gait patterns in 10-year-old boys with increasing loads when walking on a treadmill. *Gait and Posture*, *11*(3), 254-259. https://doi.org/10.1016/s0966-6362(00)00055-2

Huang, Z., Sui, X., & He, X. (2020). Spatial-temporal and kinematic characteristics of gait carrying loaded backpack with elastic straps. *Filomat*, *34*, 5207-5213.

Kang, H. (2021). Sample size determination and power analysis using the G*Power software. *Journal of Educational Evaluation for Health Professions*, *18*, 17. https://doi.org/10.3352/jeehp.2021.18.17

Kasović, M., Gomaz, L., & Zvonar, M. (2019). Correlation between relative schoolbag weight and gender and age differences of the schoolchildren in the primary school. *Hrvatski Sportskomedicinski Vjesnik*, *34*, 31-36.

Kasović, M., Štefan, L., & Zvonar, M. (2019a). Normative values for relative schoolbag weight in primary school children aged 6-14 from Czech Republic: A pilot study. *PloS One*, *14*(11), e0225741. https://doi.org/10.1371/journal.pone.0225741

Kasović, M., Štefan, L., Borovec, K., Zvonař, M., & Cacek, J. (2020). Effects of carrying police equipment on spatiotemporal and kinetic gait parameters in first year police officers. *International Journal of Environmental Research and Public Health*, *17*(16), 5750. https://doi.org/10.3390/ijerph17165750

Kasović, M., Zvonar, M., Gomaz, L., Bolčević, F., & Anton, V. (2018). Influence of schoolbag carriage on pattern changes in plantar pressure during walking among first-grade schoolchildren. *Kinesiology*, *50*, 188-193.

Khallaf, M.E. (2016). The effect of schoolbag weight on cervical posture in schoolchildren. *Türkiye Fiziksel Tıp ve Rehabilitasyon Dergisi*, *62*, 16-21.

Li, J.X., Hong, Y., & Robinson, P.D. (2003). The effect of load carriage on movement kinematics and respiratory parameters in children during walking. *European journal of Applied Physiology*, *90*(1-2), 35-43. https://doi.org/10.1007/s00421-003-0848-9

McKay, M.J., Baldwin, J.N., Ferreira, P., Simic, M., Vanicek, N., Wojciechowski, E., Mudge, A., Burns, J., & 1000 Norms Project Consortium. (2017). Spatiotemporal and plantar pressure patterns of 1000 healthy individuals aged 3-101 years. *Gait and Posture*, *58*, 78-87. https://doi.org/10.1016/j.gaitpost.2017.07.004

Negrini, S., & Carabalona, R. (2002). Backpacks on! Schoolchildren's perceptions of load, associations with back pain and factors determining the load. *Spine*, *27*(2), 187-195. https://doi.org/10.1097/00007632-200201150-00014

Pau, M., Mandaresu, S., Leban, B., & Nussbaum, M.A. (2015). Short-term effects of backpack carriage on plantar pressure and gait in schoolchildren. *Journal of Electromyography and Kinesiology*, *25*(2), 406-412. https://doi.org/10.1016/j.jelekin.2014.11.006

Perrone, M., Orr, R., Hing, W., Milne, N., & Pope, R. (2018). The impact of backpack loads on school children: A critical narrative review. *International Journal of Environmental Research and Public Health*, *15*(11), 2529. https://doi.org/10.3390/ijerph15112529

Scott, G., Menz, H.B., & Newcombe, L. (2007). Age-related differences in foot structure and function. *Gait and Posture*, *26*(1), 68-75. https://doi.org/10.1016/j.gaitpost.2006.07.009

Siambanes, D., Martinez, J.W., Butler, E.W., & Haider, T. (2004). Influence of school backpacks on adolescent back pain. *Journal of Pediatric Orthopedics*, *24*(2), 211-217. https://doi.org/10.1097/00004694-200403000-00015

Singh, T., & Koh, M. (2009). Effects of backpack load position on spatiotemporal parameters and trunk forward lean. *Gait and Posture*, *29*(1), 49-53. https://doi.org/10.1016/j.gaitpost.2008.06.006

Song, Q., Yu, B., Zhang, C., Sun, W., & Mao, D. (2014). Effects of backpack weight on posture, gait patterns and ground reaction forces of male children with obesity during stair descent. *Research in Sports Medicine (Print)*, *22*(2), 172-184. https://doi.org/10.1080/15438627.2014.881823

Van Alsenoy, K., Thomson, A., & Burnett, A. (2019). Reliability and validity of the Zebris FDM-THQ instrumented treadmill during running trials. *Sports Biomechanics*, *18*(5), 501-514. https://doi.org/10.1080/14763141.2018.1452966

Wang, H.H., Tsai, W.C., Chang, C.Y., Hung, M.H., Tu, J.H., Wu, T., & Chen, C.H. (2023). Effect of load carriage lifestyle on kinematics and kinetics of gait. *Applied Bionics and Biomechanics*, *2023*, 8022635. https://doi.org/10.1155/2023/8022635

Yamato, T.P., Maher, C.G., Traeger, A.C., Wiliams, C.M., & Kamper, S.J. (2018). Do schoolbags cause back pain in children and adolescents? A systematic review. *British Journal of Sports Medicine*, *52*(19), 1241-1245. https://doi.org/10.1136/bjsports-2017-098927

Zebris fdm. https://www.zebris.de/fileadmin/Editoren/zebris-PDF-Manuals/Medizin/Software/Alte_Versionen/Manual_zebris_FDM_1.16.x_R1_EN_web.pdf (accessed January 16, 2024).

Submitted: February 29, 2024
Accepted: May 29, 2024
Published Online First: July 9, 2024

Correspondence to:
Mario Kasović, Ph.D.
University of Zagreb, Faculty of Kinesiology
Horvaćanski zavoj 15, 10 000 Zagreb, Croatia
Phone: +385 98 315 632
Mail: mario.kasovic@kif.unizg.hr

Conflicts of interest: The authors declare that they have no conflict of interest.

Data availability: The raw data used to support the findings of this study are available from the corresponding author upon a reasonable request.

Funding statement: The project was carried out with a specific research grant from Masaryk University [MUNI/A/1314/2019].

Acknowledgments: We would like to thank all the participants for their participation in the study.

A RELIABILITY AND KINETIC ANALYSIS OF THE 10/5 REPEATED JUMP AND DROP JUMP TESTS TO DETERMINE THE USE OF A NOVEL REACTIVE STRENGTH MEASURE: THE REACTIVE QUALITY RATIO

Benjamin M. Southey[1,2], Mark J. Connick[3], Dirk R. Spits[4], Damien J. Austin[2], and Emma M. Beckman[1]

[1]School of Human Movements and Nutrition Science, The University of Queensland, St Lucia, Queensland, Australia

[2]Brisbane Lions Australian Football Club, Springfield, Queensland, Australia

[3]School of Exercise and Nutrition Sciences, Queensland University of Technology, Brisbane, Queensland, Australia

[4]Tennis Australia, Tennyson, Queensland, Australia

Original scientific paper
DOI 10.26582/k.56.2.2

Abstract:

The stretch-shortening cycle (SSC) plays an important role in locomotion, and tests such as the drop jump (DJ) and 10/5 repeated jump (RJ) are commonly used to determine this through the measure of reactive strength index (RSI). With an understanding that these tests emphasize different jump intensities and strategies, a novel measure called the reactive quality ratio (RQR) has been proposed to determine whether an individual is more dominant in RJ or DJ task. Furthermore, comparison of kinetic and temporal outputs of both tests were made during the RQR protocol. Therefore, twenty-four professional Australian footballers completed two testing sessions comprising of both the RJ and DJ test. Results indicated that whilst there was no significant difference in RSI output between RJ and DJ tests respectively (2.52±0.43 vs 2.46±0.38), there were several significant differences in underlying kinetic variables: ground contact time (180±25 vs 209±30ms), flight time (444±53 vs 500±39ms), impulse (524±67 vs 721±69 Ns), average force (2924±363 vs 2624±294N), landing RFD (73226±20555 vs 88159±35922N/s) and active stiffness (43852±11549 vs 32309±12006N/m). Additionally, good levels of reliability were found for RQR (ICC=0.76, CV=2.96%) indicating that this novel measure can be used to determine preferred jump strategy for individuals. Overall, this study confirms underlying differences between RJ and DJ tests.

Keywords: *reactive strength index, biomechanics, strength profiling, jump profiling*

Introduction

The stretch-shortening cycle (SSC) is a neuromuscular function that encompasses co-ordination of a muscle to undergo rapid eccentric contraction immediately followed by rapid concentric contraction, and is utilized in locomotion (Bosco, Ito, Komi, Luhtanen, Rahkila, Rusko, & Viitasalo, 1982; Hennessy & Kilty, 2001; Keiner, Sander, Wirth, & Hartmann, 2015; Komi & Bosco, 1978). Having greater SSC efficiency reflects the greater amounts of force that can be transferred from the eccentric to concentric contraction phase, thus reducing relative energy expenditure (Bosco & Rusko, 1983; Komi & Bosco, 1978). Reactive strength index (RSI) is a variable used to reflect the SSC and is calculated by dividing the flight time by the ground contact time, with a higher RSI indicating greater stretch-shortening cycle efficiency. Having a high RSI, requires sufficient muscle strength, to eccentrically control one's body mass upon ground contact as well as being able to produce sufficient propulsive force to create positive vertical displacement. This has been seen with moderate relationships between maximum strength and RSI, as well as stronger cohorts having higher RSI than their weaker counterparts (Jarvis, Turner, Read, & Bishop, 2021; Southey, Willshire, Connick, Austin, Spits, & Beckman, 2023b).

Plyometric tasks such as the drop jump (DJ) and 10/5 repeated jump (RJ) are typical tests used to assess RSI (Baker, Shillabeer, Brandner, Graham-Smith, Mills, & Read, 2021; Beattie, Carson, Lyons, & Kenny, 2017; Brian, Declan, & Dan, 2021; Douglas, Pearson, Ross, & McGuigan, 2018; Southey, Connick, Spits, Austin, & Beckman, 2023a). The DJ results in higher amplitude and greater intensity than the RJ due to greater landing rate of force development (RFD), power output, and ground reaction forces (GRF), causing greater muscle activations of the quadricep and gastrocnemius (Ebben, Fauth, Garceau, & Petushek, 2011; Ebben, Simenz, & Jensen, 2008). The low amplitude nature of the RJ means that it can be done more extensively with a higher volume and more rhythmical jump strategy than the DJ. These differences impact the commonality of RSI between these two tasks. Whilst RSI output may be similar between the DJ and RJ, there is little common agreement between these tests, reflecting the differences in jump strategy (Stratford, Dos'Santos, & McMahon, 2020). This difference is important for strength and conditioning coaches to understand when prescribing exercise and testing plyometric performance.

Often when prescribing plyometric exercise, particularly for developing athletes, practitioners will start with low amplitude, extensive exercises such as hopping and skipping, before progressing to more intensive exercises such as drop jumps or altitude landings (Davies, Riemann, & Manske, 2015; Ebben, 2007). This linear approach accounts for progressive overload; however, it is not always feasible for every athletic population. For instance, Australian footballers will be exposed to high training loads involving high intensity running, cutting and jumping on field throughout the preseason period (Harrison & Johnston, 2017). These athletes may benefit from exposure to high amplitude, intensive plyometrics earlier where they can develop reactive strength under this stress in a controlled environment, particularly if their extensive plyometric strength is sound. However, there is no profiling method that could guide this decision. Therefore, the reactive quality ratio (RQR) has been suggested in this study as a novel way to determine if an individual can produce reactive strength in high and/or low amplitude environments. This can then be used to determine programme prescription to develop the relative plyometric training needs of an individual. This is done by comparing the RSI between the DJ and RJ, with an RQR of 1.0 indicating an equal ability to produce reactive strength in both plyometric environments.

In order to determine the validity of the RQR, it is important to first understand the reliability of the metric and its underpinning component data, to minimize the risk of spurious results (Bishop, Shrier, & Jordan, 2023). Additionally, it is important to determine the kinetic differences in intensity between the two tests, to see if it concurs with previous findings (Ebben, et al., 2011). Therefore, the aims of this study were to: 1) to explore the reliability of the novel measure of the RQR and its component data, and 2) to observe the differences in kinetic output of the 10/5 repeated jump test and drop jump tasks whilst undertaking the RQR testing protocol. It is hypothesized that the RQR and component data will have good reliability levels, whilst the DJ would have significantly greater kinetic and temporal outputs than the RJ, despite similar RSI.

Methods

Experimental design

Participants were required to complete two testing sessions during the initial three weeks of the AFL preseason. Testing sessions were completed on a Monday and Friday during their allotted afternoon gym sessions, as this time had the greatest consistency in the training schedule. No lower body physical activity occurred on the day prior to testing, with regular field training occurring in the morning beforehand. On both days, a general warm up was completed before participants first performed one trial of the RJ, followed by three trials of the DJ off a 45cm box. Approximately 30 seconds rests was given to participants between tests as equipment was being set up. Participants were previously familiarized with the RJ and DJ tests as it was part of the regular testing schedule, which occurred 3-4 times a year over the past 1-3 years, depending on the age of the participant.

Participants

Twenty-four professional male Australian football players from a professional club volunteered for the study (age: 23.4 ± 3.2 years, range 18-30 years; body mass: 86.7 ± 6.3 kg, range 77.4-99.1 kg). Athletes either competed in the national competition, the Australian Football League (AFL) or in the reserves competition, the Victorian Football League (VFL). However, all athletes had the same training schedule. Every participant was physically fit at the time of testing and had previous strength, power and plyometric training experience as part of an AFL program (avg: 4.5 ± 3.1 years, range 1-12 years).

Gatekeeper approval from the club and player consent was attained for permission to participate and analyse data. Ethics approval was granted for this study by the university's ethics committee, application—2021/HE001957.

Testing procedures

All data were collected using a force platform (Vald Performance Force Deck Dual Platform FD4000; Newstead, Queensland, Australia) at a sampling rate of 1000Hz; capacity: 2000 kg; resolution: c.15 g/0.15 N. Reactive quality ratio (RQR) was calculated by dividing the RSI of the DJ with the RSI of the RJ. In addition to RQR and RSI variables being measured, variables such as ground contact time (GCT), flight time (FT), impulse (newtons of force produced during ground contact multiplied by time taken in seconds), peak force (the highest newton of force obtained during ground contact phase), average force (mean newtons of force measured throughout the ground contact phase), landing rate of force development (RFD) (newtons of force divided by the time taken from the initial ground contact to stabilize landing), and active stiffness (peak force divided by maximum centre of mass displacement during the concentric phase of ground contact) were also recorded for kinetic analysis.

10/5 repeated jump assessment

Participants performed one trial which required an initial countermovement jump followed by 10 consecutive reactive double-leg hops. The results from the best five hops (determined by the highest RSI) were then averaged to create the participants final value of variables. Athletes were verbally cued to "jump as high as possible, whilst minimizing ground contact time". Athletes were also instructed to hop using their ankles whilst keeping hips and knees stiff and having hands positioned on their waist. Deviation of their contact point on the force platform during the repeated hopping was common, however, only if a participant lost rhythm during his trial and could not stay on the force platform, were they required to redo the trial.

Drop jump

This test required participants to start from standing on top of a box and step off landing with both feet on the force platform before completing one reactive hop. Participants performed three trials with a drop height of 45cm. This height was to ensure that fall height, thus intensity, was significantly higher than the fall height from the RJ, which has been previously seen to be between 25 to 27cm in a similar population (Southey, et al., 2023a). An average of the three trials was used for analysis. Participants were cued to "minimize ground contact when landing and hop as high as they can" as well as "minimize knee bend on landing" and to have their hands positioned on their waist throughout the movement.

Statistical analysis

To determine the reliability of RSI and RQR methods, intraclass correlation coefficients (ICC) were calculated with 95% confidence intervals. ICC ratings were interpreted using the following criteria: <0.5 (poor), 0.5-0.75 (moderate), 0.75-0.9 (good), >0.9 (excellent) (Koo & Li, 2016). Coefficient of variation (CV) was calculated using the following formula:

(SD[Trials 1-2]/average[trials 1-2] x 100).

The average CV for squad was then calculated for both the interday and intraday tests, which was expressed as a percent. Additionally, acceptable reliability required a CV <10% (Turner, Brazier, Bishop, Chavda, Cree, & Read, 2015). Usefulness of test is a measure used to determine whether a small and moderate effect size change can be detected by the test. This was done by comparing whether the standard error measurement (SEM) was smaller than the SWC (Hopkins, 2000). The test had a usefulness rating of "good" at detecting smallest worthwhile change (SWC) if score was greater than SEM, "Ok" if they were similar, or "marginal" if less than SEM (Hopkins, 2000). SEM was calculated by dividing the between participants SD by the square root of the number of data points. SWC was calculated by multiplying between participants SD by 0.2. Moderate worthwhile change (MWC) was calculated by multiplying between participants SD by 0.5.

For group comparisons, a Shapiro Wilks test was used to determine data normality and distribution. For between trial comparisons and kinetic analysis, paired sample *t*-tests were used for parametric data, whilst Wilcoxon signed rank test was used for non-parametric data. Mean, standard deviation, median and inter-quartile range were all reported. Cliff's delta was used to calculate effect size as this calculation does not assume normal distribution of data (Macbeth, Razumiejczyk, & Ledesma, 2011). Effect size (0-0.0.146 = trivial; 0.147-0.329 = small; 0.330-0.146 = moderate; 0.147-1.0 = large) was used to indicate magnitude of difference (Romano & Kromrey, 2006). Cliff's delta also provided direction of effect size by being on a scale of -1 to +1, with positive values indicating that the RJ had higher results than the DJ. Negative effect size indicated vice versa (Macbeth, et al., 2011). All statistical analysis was completed using Rstudio (Rstudio Team, 2015), with the added package "irr" and "effsize" used to assist with intraclass correlation and effect size analysis. P value was set at <0.05.

Results

Results from the reliability and kinetic analysis can be found in Tables 1 and 2, respectively. For reliability analysis, RJ RSI data were non-parametric, whilst DJ RSI and RQR data were normally distributed when checking for normality. No statistical differences (p>.05) were seen in group comparisons between test 1 and test 2 for the RJ RSI, DJ RSI, and RQR metrics. All three metrics displayed good ICC relationships (r= >0.7) and had an acceptable CV of <10%.

For the kinetic and temporal variables, the following metrics were found to be not normally distributed: GCT, FT, and landing RFD. All other metrics were normally distributed. Significant

Table 1. Reliability analysis results

Metric	Test 1		Test 2		P value	Intra-class correlation			CV	SEM	Usefulness rating			
	Mean ± SD	Median (IQ range)	Mean ± SD	Median (IQ range)		ICC	95% CI	ICC rating			SWC	SWC rating	MWC	MWC rating
RJ RSI	2.53 ± 0.35	2.59 (2.29-2.78)	2.50 ± 0.39	2.56 (2.40-2.78)	0.348	0.86	0.71-0.94	Good	3.29%	0.08	0.07	Marginal	0.18	Good
DJ RSI	2.48 ± 0.38	2.45 (2.12-2.80)	2.46 ± 0.37	2.51 (2.27-2.70)	0.721	0.81	0.61-0.91	Good	4.02%	0.10	0.07	Marginal	0.18	Good
Reactive quality ratio (RQR)	0.98 ± 0.10	0.98 (0.94-1.04)	0.99 ± 0.11	1.00 (0.94-1.07)	0.488	0.76	0.52-0.89	Good	2.96%	0.03	0.02	Marginal	0.05	Good

Note. RJ = 10/5 repeated jump test; DJ = drop jump; SD = standard deviation; IQ = interquartile; ICC = intra-class correlation; CI = confidence interval; CV = coefficient of variation; SEM = standard error measurement; SWC = smallest worthwhile change; MWC = moderate worthwhile change; RSI = reactive strength index

Table 2. Kinetic and temporal analysis results

Metric	RJ		DJ		P value	Effect size
	Mean ± SD	Median (IQ range)	Mean ± SD	Median (IQ range)		
RSI	2.52 ± 0.43	2.57 (2.32-2.79)	2.46 ± 0.38	2.45 (2.21-2.71)	0.369	0.12 (trivial)
GCT (ms)	180 ± 25	176 (164-199)	209 ± 30	207 (186-232)	<0.0001	-0.54 (large)
FT (ms)	444 ± 53	454 (414-483)	500 ± 39	506 (472-522)	<0.0001	-0.65 (large)
Impulse (N s)	524 ± 67	521 (481-580)	721 ± 69	722 (670-773)	<0.0001	-0.97 (large)
Peak vertical force (N)	5529 ± 777	5497 (4975-5986)	5293 ± 1274	4894 (4276-6449)	0.139	0.17 (small)
Average vertical force (N)	2924 ± 363	2956 (2720-3117)	2624 ± 294	2613 (2477-2811)	<0.0001	0.48 (Large)
Landing RFD (N/s)	73226 ± 20555	70186 (59271-85432)	88159 ± 35922	84425 (58362-111641)	0.015	-0.29 (Small)
Active stiffness (N/m)	43852 ± 11549	42573 (36195-51821)	32309 ± 12006	30340 (23968-39282)	<0.0001	0.54 (Large)

Note. RJ = 10/5 repeated jump test; DJ = drop jump; SD = standard deviation; IQ = interquartile; RSI = reactive strength index; GCT = ground contact time; FT = flight time; RFD = rate of force development

statistical differences were seen between 10/5 repeated jump and drop jump tests for GCT, FT, impulse, average force, landing RFD, and active stiffness.

Discussion and conclusion

The purpose of the study was to determine the reliability of the novel RQR metric and observe any kinetic and temporal differences between the RJ and DJ whilst conducting the RQR protocol. It was hypothesized that the RQR and component RSI data would have good reliability and, whilst the RSI of the RJ and DJ would be similar, the DJ would have higher underlying kinetic outputs than the RJ. The main findings of this present study confirm the first hypothesis and partially support the second. Firstly, the reactive quality ratio (RQR) had a good intra-class correlation relationship (r=0.76) and low CV (2.96%) as a result of reliable component RSI data from the RJ and DJ. This gave strong indications that this novel measure can be used as a reliable method of reactive strength profiling. Secondly, whilst DJ had significantly higher impulse (avg: 721 ± 69 vs 524 ± 67 Ns) and landing RFD (avg: 88159 ± 35922 vs 73226 ± 20555 N/s), the RJ had significantly higher average vertical force (avg: 2924 ± 363 vs 2624 ± 294 N) and active stiffness (avg: 43852 ± 11549 vs 32309 ± 12006 N/m), highlighting the different intensities and kinetic requirements of these plyometric tasks.

The first aim of this study explored the reliability of the novel measure of reactive strength. The RQR had good ICC correlations (0.76 CI: 0.52-0.89), an acceptable CV of 2.96% and an ability to detect moderate worthwhile change. This followed similar trends with the component RSI data from the RJ and DJ, which also yielded good ICC scores of 0.86 and 0.81, respectively, along with acceptable CV of <10% (3.29 and 4.02%). Both tests could determine moderate worthwhile change, however, could not determine smallest worthwhile change as the standard error of measurement was higher than the small effect size. All these results have been similarly seen in previous literature (Baker, et al., 2021; Comyns, Flangan, Harper, Fleming, & Fitzgerald, 2017; Comyns, Flanagan, Fleming, Fitzgerald, & Harper, 2019; Markwick, Bird, Tufano, Seitz, & Haff, 2015; Stratford, et al., 2020). Thus, the RQR can be used to reliably assess reactive strength qualities of the lower limb and can be used by practitioners to guide programming prescription for athletes.

The second aim examined the kinetic and temporal differences between the RJ and DJ tests. The results confirm the findings from Stratford et al. (2020) with non-significant differences in RSI output (RJ = 2.52 ± 0.43 vs DJ = 2.46 ± 0.38), and confirm their hypothesis of different control strategies of the RJ and DJ. This was highlighted by the several underlying kinetic and temporal differences which concur with previous findings (Ebben, et al., 2011). There were large differences in GCT, with the RJ having shorter time spent on the ground compared to the DJ (avg: 180 ± 25 vs 209 ± 30 ms). Whilst the GCT for both tests engage the fast stretch-shortening cycle (fSSC) (GCT <250 ms), it was apparent that an individual can more efficiently overcome eccentric braking forces and transfer to propulsive force during the RJ. This would be due to the smaller fall height, and thus smaller eccentric force, that an individual must endure during the RJ test (Niu, Wang, Jiang, & Zhang, 2018; Verniba, Vescovi, Hood, & Gage, 2017). This was reflected with the significantly smaller impulse (avg: 524 ± 67 vs 721 ± 69 Ns) and landing RFD (avg: 73226 ± 20555 vs 88159 ± 35922 N/s) that occurred compared to the DJ, which was seen in previous research (Ebben et al., 2011). Furthermore, there were large differences in FT between the tests, with greater time in the air observed in the drop jump (avg: 500 vs 444 ms). This increased FT may be due to the greater potentiation of eccentric force from the 45 cm fall height to transfer into propulsion. This has been seen in accentuated eccentric loading protocols, where adding load during the eccentric portion of a jump can increase vertical jump performance (Lloyd, Howard, Pedley, Read, Gould, & Oliver, 2021; Sheppard, Newton, & McGuigan, 2007).

There was a large significant difference between the average vertical force between the RJ and DJ (avg: 2924 ± 363 vs 2624 ± 294 N). The larger average force experienced would reflect the smaller GCT during the RJ as there was less time to produce adequate force, relative to the flight time. Furthermore, the RJ had a significantly larger active stiffness score than the drop jump (avg: 43852 ± 11549 vs 32309 ± 12006 N/m), which indicates that there was greater concentric force produced relative to the centre of mass (CoM) displacement during GCT of the RJ test (Mudie, Gupta, Green, Hobara, & Clothier, 2017). This confirms the trend that the larger eccentric loads of the DJ required larger braking forces and/or greater CoM displacement to absorb and control bodyweight, thus reducing active stiffness output (Mudie et al., 2017). This decrease in active stiffness may have potentially come from a slight knee bend that may act to reduce eccentric load and compressive forces (Tsai, Ko, Hammond, Xerogeanes, Warren, & Powers, 2017), as the eccentric stress exceeds the activation threshold of purely the calf complex itself and requires greater engagement of the quadricep muscles (Ebben, et al., 2008; Peng, Kernozek, & Song, 2011).

Overall, when dropping from 45 cm, the DJ exposes an individual to greater eccentric stress and SSC intensity, whilst the smaller eccentric demand of the RJ allows for greater concentric force expression. Practically, this means if striving for an equal RQR of 1.0, as seen with near equal RSI outputs in this study and previous research (Stratford, et al., 2020), individuals who display a RQR greater than 1.0 indicate an ability to produce greater reactive strength in high amplitude intensive tasks such as the DJ. These individuals may benefit from greater focus on low amplitude extensive plyometric programming where there is greater room for improvement. Thus, the RQR can be used to reliably assess reactive strength qualities of the lower limb and can be used by practitioners to guide these programming intricacies.

There are a few considerations needed when interpreting results. Firstly, kinetic and temporal differences and comparisons are observed from the drop jump off a box 45 cm high. For some individuals, this height may have been above or below an optimal drop height, which could affect the highest RSI score they could attain. This is due to the concept that at optimal drop height, individuals have the optimal amount of eccentric load to enhance the concentric portion of the jump without increasing ground contact time (Tong, Chen, Xu, & Zhai, 2022). In this context, RSI output is relative to the individual; however, the purpose for the RQR protocol is to represent the plyometric intensities that one would be exposed to during training. Fundamentally, the DJ is an exercise aimed to promote high eccentric stress, introduced from the works of Verhoshanski's "shock method" (Verhoshanski, 1967), and thus should not be conducted at low intensities. Therefore, for the RQR to compare plyometric tasks with different levels of amplitude, the DJ drop height should be significantly greater than the jump height experienced in the RJ to challenge the SSC system differently. Secondly, the DJ was always assessed after the RJ, and this was to test the reliability of the RQR protocol in which practitioners could test an athlete in a single time efficient bout. Therefore, it was imperative that the testing order remained the same for all the tests, to attain reliable results. However, this would potentially have an impact on the kinetic output of the DJ and should be considered when interpreting results. Future research could explore whether this is in fact the optimal protocol in determining RQR and whether recovery time or alternating testing order would significantly impact results.

Overall, the novel measure of the reactive quality ratio (RQR), along with the RJ and DJ have been confirmed as reliable ways to measure reactive strength qualities of the lower limb; however, caution should be advised if trying to determine the smallest worthwhile change. Furthermore, whilst both the DJ and RJ are SSC tasks that are used to measure RSI, there are underlying kinetic and temporal differences between them observed during the RQR testing protocol. Whilst RSI output may be similar, the DJ has a greater eccentric demand that in turn creates a larger impulse, greater landing

RFD, and longer GCT to overcome the high eccentric load. On the other hand, the RJ has a greater average force and active stiffness, due to the lower eccentric demand, which allows for quicker absorption and transfer of eccentric energy and force into flight, represented by a shorter GCT. The RQR provides a useful way of comparing these differences that can be used by strength and conditioning practitioners to help guide athletic development programmes and plyometric training.

References

Baker, J., Shillabeer, B., Brandner, C., Graham-Smith, P., Mills, P., & Read, P. (2021). Reliability, validity, and performance characteristics of elite adolescent athletes at different stages of maturity in the 10 to 5 repeated jump test. *Pediatric Exercise Science*, *34*(1), 20-27. https://doi.org/10.1123/pes.2020-0270

Beattie, K., Carson, B.P., Lyons, M., & Kenny, I.C. (2017). The relationship between maximal strength and reactive strength. *International Journal of Sports Physiology and Performance*, *12*(4), 548-553. https://doi.org/10.1123/ijspp.2016-0216

Bishop, C., Shrier, I., & Jordan, M. (2023). Ratio data: Understanding pitfalls and knowing when to standardise. *Symmetry*, *15*(2), 318. https://doi.org/10.3390/sym15020318

Bosco, C., Ito, A., Komi, P.V., Luhtanen, P., Rahkila, P., Rusko, H., & Viitasalo, J.T. (1982). Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercises. *Acta Physiologica Scandinavica*, *114*(4), 543-550. https://doi.org/10.1111/j.1748-1716.1982.tb07022.x

Bosco, C., & Rusko, H. (1983). The effect of prolonged skeletal muscle stretch-shortening cycle on recoil of elastic energy and on energy expenditure. *Acta Physiologica Scandinavica*, *119*(3), 219-224. https://doi.org/10.1111/j.1748-1716.1983.tb07331.x

Brian, D., Declan, B., & Dan, H. (2021). Age-group differences in reactive strength and measures of intra-day reliability in female international footballers. *International Journal of Strength and Conditioning*, *1*(1), 44. https://doi.org/10.47206/ijsc.v1i1.44

Comyns, T., Flangan, E., Harper, D., Fleming, S., & Fitzgerald, E. (2017). Interday reliability and usefulness of reactive strength index derived from the ten to five repeated jump test. *Journal of Sports Sciences*, *35*(Sup2), S80. doi: 10.1080/02640414.2017.1378421

Comyns, T.M., Flanagan, E.P., Fleming, S., Fitzgerald, E., & Harper, D.J. (2019). Interday reliability and usefulness of reactive strength index derived from two maximal rebound jump tests. *International Journal of Sports Physiology and Performance*, *14*(9), 1200-12041-17. https://doi.org/10.1123/ijspp.2018-0829

Davies, G., Riemann, B. L., & Manske, R. (2015). Current concepts of plyometric exercise. *International Journal of Sports Physical Therapy*, *10*(6), 760-786.

Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2018). Kinetic determinants of reactive strength in highly trained sprint athletes. *Journal of of Strength and Conditioning Researcg*, *32*(6), 1562-1570. https://doi.org/10.1519/JSC.0000000000002245

Ebben, W.P. (2007). Practical guidelines for plyometric intensity. *NSCA's Performance Training Journal*, *6*,12-16.

Ebben, W.P., Fauth, M.L., Garceau, L.R., & Petushek, E.J. (2011). Kinetic Quantification of Plyometric Exercise Intensity. *Journal of Strength and Conditioning Research*, *25*(12) 3288-3298. doi: 10.1519/JSC.0b013e31821656a3

Ebben, W.P., Simenz, C., & Jensen, R.L. (2008). Evaluation of plyometric intensity using electromyography. *Journal of Strength and Conditioning Research*, *22*(3), 861-868. https://doi.org/10.1519/JSC.0b013e31816a834b

Harrison, P.W., & Johnston, R.D. (2017). Relationship between training load, fitness, and injury over an Australian rules football preseason. *Journal of Strength and Conditioning Research*, *31*(10), 2686-2693. https://doi.org/10.1519/jsc.0000000000001829

Hennessy, L., & Kilty, J. (2001). Relationship of the stretch-shortening cycle to sprint performance in trained female athletes. *Journal of Strength and Conditioning Research*, *15*(3), 326-331.

Hopkins, W.G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*(1), 1-15. https://doi.org/10.2165/00007256-200030010-00001

Jarvis, P., Turner, A., Read, P., & Bishop, C. (2021). Reactive strength index and its associations with measures of physical and sports performance: A systematic review with meta-analysis. *Sports Medicine*, *52*, 301-330 (2022). https://doi.org/10.1007/s40279-021-01566-y

Keiner, M., Sander, A., Wirth, K., & Hartmann, H. (2015). Differences in the performance tests of the fast and slow stretch and shortening cycle among professional, amateur and elite youth soccer players. *Journal of Human Sport and Exercise*, *10*(2), 563-570. https://doi.org/10.14198/jhse.2015.102.03

Komi, P.V., & Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. *Medicine and Science in Sports*, *10*(4), 261-265.

Koo, T.K., & Li, M.Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Lloyd, R.S., Howard, S.W., Pedley, J.S., Read, P.J., Gould, Z. I., & Oliver, J.L. (2021). The acute effects of accentuated eccentric loading on drop jump kinetics in adolescent athletes. *The Journal of Strength and Conditioning Research*. doi: 10.1519/JSC.0000000000003911

Macbeth, G., Razumiejczyk, E., & Ledesma, R. (2011). Cliff's Delta Calculator: A non-parametric effect size program for two groups of observations. *Universitas Psychologica*, *10*, 545-555. https://doi.org/10.11144/Javeriana.upsy10-2.cdcp

Markwick, W.J., Bird, S.P., Tufano, J.J., Seitz, L.B., & Haff, G.G. (2015). The intraday reliability of the Reactive Strength Index calculated from a drop jump in professional men's basketball. *International Journal of Sports Physiology and Performance*, *10*(4), 482-488. https://doi.org/10.1123/ijspp.2014-0265

Mudie, K.L., Gupta, A., Green, S., Hobara, H., & Clothier, P.J. (2017). A comparison of vertical stiffness values calculated from different measures of center of mass displacement in single-leg hopping. *Journal of Applied Biomechanics*, *33*(1), 39-47. https://doi.org/10.1123/jab.2016-0037

Niu, W., Wang, L., Jiang, C., & Zhang, M. (2018). Effect of dropping height on the forces of lower extremity joints and muscles during landing: A musculoskeletal modeling. *Journal of Healthcare Engineering*, *2018*, 2632603. https://doi.org/10.1155/2018/2632603

Peng, H.-T., Kernozek, T.W., & Song, C.-Y. (2011). Quadricep and hamstring activation during drop jumps with changes in drop height. *Physical Therapy in Sport*, *12*(3), 127-132. https://doi.org/https://doi.org/10.1016/j.ptsp.2010.10.001

Romano, J., & Kromrey, J. (2006). Appropriate statistics for ordinal level data: Should we really be using t-test and Cohen's d for evaluating group differences on the NSSE and other surveys? Annual Meeting of the Florida Association of Institutional Research, .

Sheppard, J., Newton, R., & McGuigan, M. (2007). The effect of accentuated eccentric load on jump kinetics in high-performance volleyball players. *International Journal of Sport Science and Coaching*, *2*(3), 267-273. https://doi.org/10.1260/174795407782233209

Southey, B., Connick, M., Spits, D., Austin, D., & Beckman, E. (2023a). Determining interday & intraday reliability of the 10/5 repeated jump test in elite Australian footballers. *International Journal of Strength and Conditioning*, *3*(1). https://doi.org/10.47206/ijsc.v3i1.181

Southey, B., Willshire, M., Connick, M.J., Austin, D., Spits, D., & Beckman, E. (2023b). Reactive strength index as a key performance indicator in different athlete populations—A systematic review. *Science and Sports*, *39*(2), 129-143. https://doi.org/https://doi.org/10.1016/j.scispo.2023.01.004

Stratford, C., Dos'Santos, T., & McMahon, J. (2020). A comparison between the drop jump and 10/5 repeated jumps test to measure the reactive strength index. *Professional Strength and Conditioning*, *57*, 23-28.

Tong, Z., Chen, W., Xu, H., & Zhai, F. (2022). Optimal loading height: A practical research of drop jump from biomechanics. *Journal of Healthcare Engineering*, *2022*, 4173639. https://doi.org/10.1155/2022/4173639

Tsai, L.C., Ko, Y.A., Hammond, K.E., Xerogeanes, J.W., Warren, G.L., & Powers, C.M. (2017). Increasing hip and knee flexion during a drop-jump task reduces tibiofemoral shear and compressive forces: Implications for ACL injury prevention training. *Journal of Sports Science*, *35*(24), 2405-2411. https://doi.org/10.1080/02640414.2016.1271138

Turner, A., Brazier, J., Bishop, C., Chavda, S., Cree, J., & Read, P. (2015). Data analysis for strength and conditioning coaches: Using Excel to analyze reliability, differences, and relationships. *Strength and Conditioning Journal*, *37*(1), 76-83. https://doi.org/10.1519/SSC.0000000000000113

Verhoshanski, Y. (1967). Are depth jumps useful. *Track and Field*, *12*(9), 28-35.

Verniba, D., Vescovi, J.D., Hood, D.A., & Gage, W.H. (2017). The analysis of knee joint loading during drop landing from different heights and under different instruction sets in healthy males. *Sports Medicine—Open*, *3*(1), 6. https://doi.org/10.1186/s40798-016-0072-x

Submitted: October 18, 2023
Accepted: June 29, 2024
Published Online First: November 9, 2024

Correspondence to:
Benjamin M. Southey
School of Human Movements and Nutrition Science,
The University of Queensland, St Lucia,
Queensland, Australia
Brisbane Lions Australian Football Club, Springfield,
Queensland, Australia
ORCID: 0000-0003-1963-8576
Phone: (+61) 0457155571
Email: b.southey@uq.net.au

Acknowledgements

The authors would like to thank the participants for their involvement in this study.

Declaration of interest

All authors declare no conflict of interest.

RELATIONSHIP BETWEEN PITCH VELOCITY AND PHYSICAL FITNESS IN ELITE BASEBALL PITCHERS

Zhigang Yang[1] and Lina Wang[2]

[1]Department of Physical Education, Fudan University, China
[2]Sanda University, China

Original scientific paper
DOI 10.26582/k.56.2.3

Abstract:

The purpose of this study was to determine the key physical conditions needed for a pitcher by studying the relationship between pitch velocity and a set of selected physical fitness variables. Seventeen baseball coaches and experts were recruited to recommend and select key variables determining pitchers' physical fitness. After a three-round inquiry, 16 variables were identified. Internal consistency reliability (Cronbach's α reliability) was 0.826 and the content validity ratio was 1. A total of 27 male elite baseball pitchers (22.97±4.01 years old), who came from Chinese professional teams, were tested by the 16 variables selected and their pitch velocity was determined after a warm-up. The correlations between pitch velocity and the other 15 variables were computed. The coefficient of the correlation among pitch velocity and max distance long toss, jump lunge with load, and shoulder internal rotation was 0.628 ($p<.05$), 0.369 ($p<.05$), and -0.312($p<.05$), respectively. A follow-up regression analysis found that three variables explained 42.9% of the pitch velocity variance. The pitch velocity was moderately related to their max distance long toss and somewhat correlated with jump lunge with load and shoulder internal rotation.

Keywords: *pitching speed, strength and conditioning, fitness assessment*

Introduction

Pitchers are the soul and core of a baseball team, and they often play a key role in a baseball game. About 65 to 85% of a winning team's success is attributed to pitchers (Reiff, 1971). Pitch velocity (PV) is very important for success in pitching. There are some factors influencing PV, such as wind speed, muscle strength, psychology, umpire bias in judgment, weather, and so on (Parsons, Sulaeman, Yates, & Hamermesh, 2011). From the performance perspective, PV has traditionally been accepted as a criterion to assess quality of a pitcher (Werner, Suri, Guido, Meister, & Jones, 2008). And it is important that pitchers generate the throwing force at the same release point (Perkin, 2014).

The biomechanics underlying the skill of pitching performance has been the focus of numerous studies, aiding pitchers in understanding their needs and how to enhance their skills (Fortenbaugh, Fleisig, & Andrews, 2009). Baseball pitchers, exposed to high stress on their throwing elbow and shoulder because of repetitive pitching, would frequently get injured (Olsen, Fleisig, Dun, Loftice, & Andrews, 2006). Baseball pitchers lose pitching strength during the game and suffer from pain in their throwing elbow and shoulder after it (Fleisig, et al., 1996). Fatigue also reduces the pitcher's PV (Escamilla, et al., 2007). Therefore, improving their strength is very important.

Furthermore, it was proved that strength was associated with ball velocity although the contribution of particular muscle groups was not exactly clear (Bartlett, Storey, & Simons, 1989). Pugh, Kovaleski, Heitman, and Pearsall (2001) reported that arm and grip strength correlated with PV ($p\leq.05$) for the experienced group, whereas arm strength correlated with PV for the inexperienced group ($p\leq.05$). Lower body strength is as important as upper body strength because pitching process is a kinetic chain in which strength is transferred from the lower to the upper body (Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001; Seroyer, et al., 2020; Stodden, Fleisig, McLean, & Andrews, 2005; Werner, et al., 2008). A similar result was obtained by MacWilliams, Choi, Perezous, Chao, and McFarland (1998), who found that maximum linear wrist velocity correlated highly with the maximal push-off force of the throwing leg in the direction of the pitch. McEvoy and Newton (1998) considered that ballistic resistance training can improve baseball pitching. However, the results obtained by Magnusson, Gleim, and Nicholas

(1994) showed that there was significant weakness in the supraspinatus, the external rotators, and the abductors in the professional baseball pitchers.

It was widely accepted that pitchers should be trained by conventional weight training (Bailery, 1988) and plyometric training (Burgener, 1989), which were helpful to improve PV, however, what are the best methods still remains unclear. Byram et al. (2010) tested the pitchers on the weakness of external rotation and supraspinatus strength in preseason because that weakness increased the risk of injury. Magnusson et al. (1994) identified that three glenohumeral muscles: supraspinatus, external rotators, and abductors, required in pitching motion, were weak in professional baseball pitchers. Thus, internal rotation strength was stronger than external rotation (Ellenbecker & Mattalino, 1997).

Undoubtedly, PV is associated with pitchers' physical fitness (PF). And it is very important to select specific and effective training methods to improve PV. While previous research has focused on the methods of the specific PF, little attention has been given to the relationship and prediction between PV and PF. Generating consistent maximum ball velocity is an important factor for a baseball pitcher's success.

However, there are very few sport-specific studies examining the relationship between field tests or exercises and pitching velocity. This lack of knowing a correlation between PF and PV is complex due to which some coaches use methods that are only subjectively believed to improve ball speed.

The purpose of this paper was to determine the key PF components needed for a pitcher by studying the relationship between PV and a set of selected PF variables, which, in turn, should help coaches design more effective training programmes to improve pitchers' PF. The results and information derived from this study may be helpful for coaches, physical therapists, and athletic trainers who directly interact with baseball players.

Methods

In the study, a survey in the form of a questionnaire was utilized. When a baseball tournament in China was held, 17 baseball coaches and experts were recruited to recommend and select key variables that determine pitcher's PF. After a three-round inquiry, 16 variables were identified. Internal consistency reliability (Cronbach's α reliability) was 0.826 and the content validity ratio (CVR) was 1 (CVR = [Ne-N/2] / [N/2], in which the Ne was the number of panelists indicating "fairly essential" and N was the total number of panelists (Lawshe, 1975). The sample size (Pocock, 1983) was based on the formula: $n=Z^2 P (1-P)/d^2$ (Z=1.96, 95% confidence interval [CI]; P=prevalence; d=precision) (Daniel, 1999). A total of 27 male elite baseball pitchers (age: 22.97±4.01 years; PV: 132.38±5.77km/h; training experience: 11.52±3.24 years), who came from Chinese professional teams, were tested by the 16 variables selected and their pitch velocity was measured. The variables included PV (km/h), 10m sprint (s) (10S), 5-different-direction sprints (s) (DDS), reaction time (s) (RT), max distance long toss (m) (MDLT), standing long jump (m) (SLJ), standing triple jump (m) (STJ), jump lunge with load (s) (JLWL), medicine ball side throw (m) (MBST), twisting crunch (num) (TC), shoulder internal rotation (num) (SIR), modified plank (point) (MP), double unders (num) (DU), stork balance stand test (s) (SBST), deep squat test (point) (DS), and forward split (cm) (FS). After an adequate warm-up including 5-minute jogging, 5-minute related dynamic stretching exercises and 5-minute specific warm-up (throwing, jumping, lifting, sprinting, deep squat, and lunge), 27 male baseball pitchers were tested, and assessed during three days according to test rules (NSCA, 2008). Pitchers had a 5-min between-variables rest. Before the study, all athletes were informed of the study purpose, risks, and benefits and they agreed to participate. All procedures were in compliance with the 1975 Declaration of Helsinki as revised in 2000.

Pitch velocity (PV). PV was assessed between the pitcher's mound and home plate (18.44m). The tester with a radar gun stood behind the home plate and was protected by net. The pitch velocity was measured when the baseball passed through the home plate. After an adequate general warm-up and specific related stretching exercises, they started to throw with maximum effort with approximately a 60-second rest between each repetition. Then, only the three best throws that passed the strike zone were recorded, and their mean was computed.

10m sprint (10S). Sprint performance over 10m was recorded by a stopwatch (Made in China). The tester promptly triggered the hand-release switch the instant the pitchers left the starting line, and stopped it when they crossed the terminal line. After an adequate general warm-up and specific related stretching exercises, the pitchers were permitted to do several specific runs. They ran twice with maximum effort with a 60-second rest between runs. The time was recorded, and mean was computed.

Five different direction sprints (DDS). After an adequate warm-up and specific related stretching exercises, the pitchers started from the defensive position O, sprinted to A and with the glove touched logo A, then quickly returned to O. Next, they started from the defensive position O, sprinted to B, C, D and E like A and B, as shown in Figure 1. The pitcher was permitted to try once. The tester used the stopwatch (Made in China) to record the time from start to finish. The pitchers were

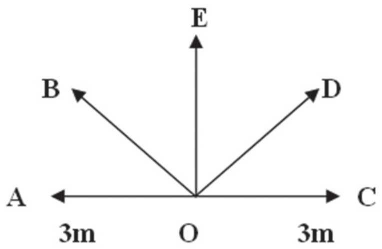


Figure 1. Different direction sprints.

permitted to attend twice with maximum effort with a 120-second rest between runs. The time was recorded, and mean was computed.

Reaction time (RT). The tester used the software called Fastball Reaction Time to measure reaction time. The pitcher was permitted to try once before he was measured. The reaction time was measured ten times, and mean was computed.

Max distance long toss (MDLT). After an adequate warm-up and specific related stretching exercises, the pitcher stood on the home plate and threw three times a flat-ground throwing as far as possible with approximately a 60-second rest between each repetition. Participants were instructed to throw hard on a horizontal line. The tester recorded the best maximum distance among the three throws.

Standing long jump (SLJ). After an adequate warm-up and the specific related stretching exercises, the pitcher stood behind the jump line and jumped three times as far as possible with approximately a 60-second rest between each repetition. The tester recorded the farthest distance among the three jumps.

Standing triple jump (STJ). After an adequate warm-up and the specific jump, the pitcher stood behind the jump line and jumped three times as far as possible in three strides with approximately a 60-second rest between each repetition. The tester recorded the farthest distance among the three jumps.

Jump lunge with load (JLWL). After an adequate general warm-up and the specific related stretching exercises, the pitcher stood with the feet shoulder-width apart and loaded a 20kg barbell. He started to take a big step forward with his right leg in a lunge position as soon as he had heard the signal. He shifted weight forward on this leg then jumped up quickly switching the position of his feet and legs while mid-air so his right leg moved backwards and his left leg moved forwards. This movement pattern is repeated during 30s. The pitcher had a 5-minute rest between two tests. The highest number of correct lunges was recorded.

Medicine ball side throw (MBST). After an adequate warm-up and the specific related stretching exercises, the pitcher held a 3kg medicine ball with two hands and threw it laterally three times with maximum effort with approximately a 60-second rest between each repetition. The tester recorded the farthest distance.

Twisting crunch (TC). After an adequate warm-up and the specific related stretching exercises, the pitchers lay on his back on the mat with the knees flexed at 90 degrees. When pitchers heard the start signal, they immediately raised the upper body off the mat and used the right elbow to touch the left knee joint, after touching the left knee, lower down the upper body and raise it again to touch the right knee. The tester recorded the time and frequency.

Shoulder internal rotation (SIR). After an adequate warm-up and the specific related stretching exercises, pitchers should stand with their shoulders externally rotated and elbows bent at 90°. Keeping the shoulder away from the body, they rotated it forward, keeping the elbows bent at 90°. Return the elastic band to the starting position. Pitchers used a 5LB elastic band with internal rotation at 90° thus simulating pitching shoulder motion. Pitchers should perform as many moves as possible in 10 seconds with approximately a 120-second rest between each repetition. The tester recorded a higher number of moves (frequency) within 10 seconds between two repetitions.

Modified plank (MP). After an adequate warm-up and the specific related stretching exercises, the pitcher did seven kinds of plank. First, the pitcher did a normal plank for 15 seconds. The next part of the test starts immediately after the 15-second plank. In the second step, the pitcher extended his left arm forward keeping it parallel to the ground and holding this position for 15 seconds then returned it to the starting position. In the third step, the pitcher extended the alternating arm and held the position then returned it to the starting position. In the fourth step, the pitcher extended the left leg and kept it parallel to the ground while holding this position for 15 seconds then returned it to the starting position. In the fifth step, the pitcher did the same with his right leg, and then returned it to start. In the sixth step, the pitcher extended the left arm and the right leg and kept it parallel to the ground for 15 seconds. In the last step, the pitcher executed the same with his right arm and left leg, holding them straight out for 15 seconds. The pitcher got one point after he accurately completed one kind of the described movement. The pitcher should stop this test immediately if his body cannot stay in the same plane and if he cannot keep his limbs straight and balanced at any point during the test. If the pitcher fell over or lost his balance at any point during the test, stop. Record the highest score achieved by the pitcher after the test.

Double unders (DU). After an adequate general warm-up and the specific related stretching exercises, the pitchers started to jump rope for 30 seconds—the rope should pass beneath his feet twice while he is in the air. The tester recorded the frequency.

Stork balance stand test (SBST). After an adequate general warm-up and the specific related stretching exercises, the pitchers lifted the right foot near the left knee joint. As soon as they heard "start", they lifted the left heel off the ground and stood on the balls of the left foot. The tester recorded the time until their left heel touched the ground, or the right foot left the position.

Deep squat (DS). After an adequate general warm-up and the specific related stretching exercises, the pitcher assumed parallel stance with the feet shoulder-width. The feet should be in the sagittal plane with no lateral outturn of the toes. He lifted a baseball bat on the top of the head and slowly lowered himself into the deepest possible squat position, the heels on the floor, head and chest facing forward and the bat maximally pressed overhead. The knees should be aligned over the feet with no valgus collapse. After the tester observed them from the front and side, he gave a score from one to three by FMS (Functional Movement Screen). Three points is the highest score.

Forward split (FS). After an adequate general warm-up and the specific related stretching exercises, the pitchers slowly started to forward split the legs with maximum effort. The tester measured the distance three times between bifurcation and the ground. The shortest distance was recorded.

All the data were presented as mean±SD. The effects were analyzed by SPSS18.0, and the correlations between PV and other 15 variables were computed. Furthermore, the regression analysis was used between PV and the other variables. A criterion of .05 level was used to decide statistical significance, and a level of r was used to decide statistical correlation.

Results

As can be seen in Table 1, 16 variables of the pitchers' PF were measured. We computed the mean (M) and standard deviation (SD).

As revealed in Table 1, there was a moderately high correlation between PV and MDLT ($r=0.628$, $p<.05$), a moderate correlation between PV and JLWL ($r = 0.369$, $p<.05$), and a low correlation between PV and SIR ($r = -0.312$, $p<.05$). There was almost no relationship between PV and other variables.

As can be seen in Table 2, the R square was .429. MDLT, JLWL, and SIR explained 42.9% of the PV variance. The ANOVA demonstrated that the regression was significant and meaningful ($F=9.948$, $p<.001$) (Table 3). As provided in Table 4, there was a regression analysis. PV can be computed by a formula that is a= 92.628+.409 (MDLT).

Table 1. Correlations between PV and 15 selected variables

ID	Variables	Construct	M±SD	*SD*	*r*
1	PV (km/h)	Speed	132.381	5.772	
2	10S(s)	Quickness	1.774	.069	.069
3	DDS (s)	Quickness	11.213	.688	.125
4	RT (s)	Reaction speed	.208	.020	-.076
5	MDLT (m)	Arm strength	97.786	7.707	.628*
6	SLJ (m)	Lower extremity power	2.671	.095	.141
7	STJ (m)	Lower extremity power	8.538	.294	.171
8	JLWL (s)	Body fast strength	40.119	3.749	.369*
9	MBST (m)	Core power	14.107	1.102	-.106
10	TC (num)	Core strength	31.548	2.769	-.062
11	SIR (num)	Upper extremity fast strength	33.714	1.701	-.312*
12	MP (point)	Core stability	6.262	.701	.174
13	DU (num)	Coordination	58.357	5.170	-.188
14	SBST (s)	Balance	25.691	10.547	-.103
15	DST (point)	Functional movement	2.500	.552	-.008
16	FS (cm)	Core flexibility	14.452	6.740	.075

Note. s=seconds, m = meters, num = number; *p<.05)

Table 2. R Square

Model		R	R square	Adjusted R square	Std. error of the estimate	R square change	Change statistics			
							F change	df1	df2	Sig. F change
dimension0	1	.655[a]	.429	.383	4.53232	.429	9.498	3	38	.000

Note. a. predictors: (Constant), MDLT, JLWL, SIR.

Table 3. Regression coefficients[a]

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	95.0% confidence interval for B	
		B	Std. error	Beta			Lower bound	Upper bound
1	(Constant)	92.628	21.848		4.240	.000	48.399	136.857
	SIR	-.297	.450	-.087	-.661	.513	-1.207	.613
	JLWL	.244	.205	.159	1.192	.241	-.170	.659
	MDLT	.409	.101	.546	4.050	.000	.204	.613

Note. a. dependent variable: PV, MDLT, JLWL, SIR.

Discussion and conclusions

The pitcher has an essential role in the baseball team, and PV is one of the most important tools for the assessment of a successful pitcher (Werner, et al., 2008). Sixty-five to eighty-five percent of a winning team's success derives from effective pitching (Reiff, 1971).

A higher PV means that the batter does not have enough time to decide whether to swing or not. However, the level of PV in China is lower than that in Japan, Korea, or US. Therefore, we are seeking to find some effective training methods to improve Chinese pitchers' PV. There are many different training methods for PV development that have a certain effect, but it is hard to say which one is more effective. Thus, as can be seen in the results, 15 variables were chosen and analyzed using a test, survey, and statistical software. PV performance was moderately and highly related to the participants' max distance long toss, and moderately correlated with 30-second lunge lift and shoulder internal rotation. Max distance long toss is a good way to improve PV and improve strength of pitching because it can integrate the lower extremities, pelvis, trunk, arm, and hand to throw the baseball (Anz, et al., 2010; Fleisig, Hsu, Fortenbaugh, Cordover, & Press, 2013; Stodden, Fleisig, McLean, Lyman, & Andrews, 2001).

Long-toss baseball throwing may improve the PF of healthy pitchers providing greater arm strength, arm flexibility, arm speed, and ultimately pitch speed (Fleisig, Bolt, Fortenbaugh, Wilk, & Andrews, 2011). However, throwing max distance means a long toss and that method is somewhat controversial in professional baseball. Lots of professional teams have limited their pitchers to throwing a maximum distance of 120ft and insisted they only throw the straight baseball not arched as you want.

According to the theory of physics, velocity (v) = distance (d)/time (t). Velocity cannot be defined completely as a uniform motion because the baseball does not travel in a straight line but in an arc one. There are some differences between MDLT and the pitching mechanics of high ball velocity, such as elbow flexion and shoulder external rotation are greater for the max distance long toss in cooked position. At the time of ball release, both the forward trunk tilt and front knee flexion are smaller for the max distance long toss. The pelvis, upper trunk rotational velocities, elbow extension velocity, peak elbow varus torque, and peak shoulder internal rotation torque are all greater than in the fastball pitch. But there is a similarity in ball velocity. Thus, these throws may be beneficial in pitcher training (Fleisig, et al., 1996).

It is very important for PV that the proper and efficient coordination strength exists among the upper limbs, the core, and the lower limb (Clements, Ginn, & Henley, 2001). Jump lunge with a light load is a good way to improve the pitchers' kinetic chain that is most important to PV (Escamilla, Fleisig, Barrentine, Andrews, & Moorman, 2002).

Leg power and strength are also very important for pitchers because the force of throwing is generated from the ground. It has been proven to have a positive correlation with pitching and throwing. Many PF coaches from Major League Baseball think that lower extremity exercise is the most important exercise for baseball players (Spaniol, 2009).

Stride knee extension is also essential to pitchers who want to pitch high velocity during the ball release (Matsuo, et al., 2001). Another study showed stride ground reaction forces were strongly correlated with pitching velocity (McNally, Borstad, Oñate, & Chaudhari, 2015). The movement of JLWL is similar to the stride of the pitching movement. Thus, JLWL is also a good one of the specific strength training methods.

Upper extremity, including shoulder adduction, elbow extension, and wrist extension, can significantly predict PV and it can also contribute 51% to PV (Toyoshima, Hoshikawa, Miyashita, & Oguri, 1974). Shoulder external and internal rotations are both contributors to increasing ball velocity. A study showed that high-velocity pitchers had significantly greater shoulder external rotation during the arm-cocking phase compared to low-velocity pitchers (Matsuo, et al., 2001). Shoulder external rotation may cause stretch-shortening cycles (SSC) in shoulder muscles during pitching and throwing (Feltner, 1989).

Shoulder internal rotation (SIR) is one of the ballistic resistance trainings for PV improvement. Kibler (1994) contends scapula plays a vital role in maintaining the kinetic chain during overarm motion because about 54% of the total force is generated in the arm. McEvoy and Newton (1998) claimed that ballistic resistance training can significantly increase performance in baseball pitching. Baseball throwing speed is highly related to elbow extensor and SIR strength (Clements, et al., 2001). Nevertheless, the movement of quick shoulder internal rotation with an elastic band is similar to pitching, and it can improve shoulder's strength avoiding shoulder injury. Because pitchers lost pitching strength and suffered from pain after training sessions and games, it was more essential to improve shoulder and elbow strength than strength of other body parts (Yanagisawa, et al., 2003). A study (Huang, Wei, Jung-Chi, Hsu, & Chang, 2005) revealed that internal rotators' (IR) strength was greater than strength of external rotators (ER) in pitchers, and there was a 70% strength loss in IR when the pitchers were assessed in endurance. Adolescent and pre-pubescent baseball pitchers had relatively weaker shoulder ERs in muscle endurance. SIR with an elastic band can simulate the movement of both the IR and ER in the shoulder and enhance IR and ER strength.

Studies on resistance training including free weight (Popescue, 1975), elastic bands (Escamilla, et al., 2010), medicine balls (Newton & McEvoy, 1994), and isokinetic machines (Wooden, et al., 1992) have shown more positive improvements in throwing and pitching velocity. However, a study (Rodgers & Whipple, 1990) has shown the use of heavy loads cannot increase PV in the neuromuscular system.

PV in elite pitchers with both the pelvis (662 ±148°/s) and upper torso (1180 ± 294°/s) is associated with increased pelvis and upper torso velocities (Fleisig, et al., 1996). Pitchers who had greater lateral trunk flexion at maximum external rotation had higher ball velocity (Oyama, et al., 2013). Improved trunk strength will likely generate higher trunk velocity (Ishida & Hirano, 2004).

Medicine ball (MB) training can improve upper torso velocity better than other methods such as seated band rotation, lying cross-over, and twister (Stodden, Campbell, & Moyer, 2008). MB training as both ballistic and plyometric can improve baseball players to generate powerful, sequential, and rotational actions (Newton & McEvoy, 1994). It is proved that the medicine ball test is valid and reliable for evaluating core power (Stockbrugger & Haennel, 2001) because forces and energy from the hips will be transferred through the torso to the upper extremity when the pitcher pitches the baseball or MB (Raeder, Fernandez-Fernandez, & Ferrauti, 2015). MB training closely simulates the sequential stretch-shortening cycle of energy transfer, and it has been shown to help improve pitch velocity in baseball games (Raeder et al., 2015).

Moderate relationships were observed between PV and rotational MB throw velocity ($r=0.62$, $p=.02$) (Taniyama, Matsuno, Yoshida, Pyle, & Nyland, 2021). MB is a good training method for baseball pitchers, but the medicine ball showed no significant increase in PV but a significant increase in strength because it did not improve the neuromuscular qualities of force output and rate of force development (RFD) (Newton & McEvoy, 1994). Similarly, the correlation between medicine ball side throw and PV is very low ($r=-.106$). Therefore, pitchers should focus on core force output and RFD.

As revealed in the results, the PV formula was built by regression analysis. Thus, we got the statistical model for PV. The formula ($a= 92.628+.409b$) can be used to compute the PV. Descriptive statistics of PV and of the selected variables, as well as their correlations, are summarized. A follow-up regression analysis found that, together, MDLT, JLWL, and SIR explained 42.9% of PV variance.

In conclusion, PV was moderately related to pitchers' MDLT and somewhat correlated with JLWL and SIR. Therefore, to improve PV, the focus of the training should be on improving the pitchers' arm strength, lower body power, upper body fast strength, and core RFD.

Limitation

There are some limitations in that the sample size of pitchers was relatively small, so it is hard to generalize which PF methods of the PV development are better. In future research, we will be looking for PV training methods applied to different level athletes and female pitchers, and analyze the relationship between PV and PF or specific fitness on the basis of different country's pitchers.

References

Anz, A.W., Bushnell, B.D., Griffin, L.P., Noonan, T.J., Torry, M.R., & Hawkins, R.J. (2010). Correlation of torque and elbow injury in professional baseball pitchers. *The American Journal of Sports Medicine, 38*(7), 1368-1374. https://doi.org/10.1177/0363546510363402

Bailery, D.W. (1988). Baseball conditioning program. *NSCA Journal*, *10*(4), 48-49.

Bartlett, L.R., Storey, M.D., & Simons, B.D. (1989). Measurement of upper extremity torque production and its relationship to throwing speed in the competitive athlete. *The American Journal of Sports Medicine, 17(1),* 89-91. https://doi.org/10.1177/036354658901700115

Burgener, M. (1989). Palormar Community College baseball conditioning program. *NSCA Journal*, *11*(3), 50-12.

Byram, I.R., Bushnell, B.D., Dugger, K., Charron, K., Harrell, F.E., Jr, & Noonan, T.J. (2010). Preseason shoulder strength measurements in professional baseball pitchers: Identifying players at risk for injury. *The American Journal of Sports Medicine*, *38*(7), 1375-1382.

https://doi.org/10.1177/0363546509360

Clements, A.S., Ginn, K.A., & Henley, E. (2001). Correlation between muscle strength and throwing speed in adolescent baseball players. *Physical Therapy in Sport*, 2(3), 123-131.

https://doi.org/10.1054/ptsp.2000.0025

Daniel, W.W. (1999). Biostatistics: A foundation for analysis in the health sciences (7th ed.). New York: John Wiley & Sons.

Ellenbecker, T.S., & Mattalino, A.J. (1997). Concentric isokinetic shoulder internal and external rotation strength in professional baseball pitchers. *The Journal of Orthopaedic and Sports Physical Therapy*, *25*(5), 323-328. https://www.jospt.org/doi/10.2519/jospt.1997.25.5.323

Escamilla, R.F., Barrentine, S.W., Fleisig, G.S., Zheng, N., Takada, Y., Kingsley, D., & Andrews, J.R. (2007). Pitching biomechanics as a pitcher approaches muscular fatigue during a simulated baseball game. *The American Journal of Sports Medicine*, *35*(1), 23-33. https://doi.org/10.1177/0363546506293

Escamilla, R., Fleisig, G., Barrentine, S., Andrews, J., & Moorman, C. 3rd (2002). Kinematic and kinetic comparisons between American and Korean professional baseball pitchers. *Sports Biomechanics*, *1*(2), 213-228. https://doi.org/10.1080/14763140208522798

Escamilla, R.F., Fleisig, G.S., Yamashiro, K., Mikla, T., Dunning, R., Paulos, L., & Andrews, J.R. (2010). Effects of a 4-week youth baseball conditioning program on throwing velocity. *Journal of Strength and Conditioning Research*, *24*(12), 3247-3254. https://doi: 10.1519/JSC.0b013e3181db9f59

Feltner, M.E. (1989). Three-dimensional interactions in a two-segment kinetic chain. Part II: Application to the throwing arm in baseball pitching. *International Journal of Sport Biomechanics*, *5*(4), 420-450. https://doi: 10.1123/IJSB.5.4.420

Fleisig, G.S., Bolt, B., Fortenbaugh, D., Wilk, K.E., & Andrews, J.R. (2011). Biomechanical comparison of baseball pitching and long-toss: Implications for training and rehabilitation. *The Journal of Orthopaedic and Sports Physical Therapy*, *41*(5), 296-303. https://www.jospt.org/doi/10.2519/jospt.2011.3568

Fleisig, G.S., Escamilla, R.F., Andrews, J.R., Matsuo, T., Satterwhite, Y.E., & Barrentine, S.W. (1996). Kinematic and kinetic comparison between baseball pitching and football passing. *Journal of Applied Biomechanics, 12(2)*, 207-224. https://doi.org/10.1123/jab.12.2.207

Fleisig, G.S., Hsu, W.K., Fortenbaugh, D., Cordover, A., & Press, J.M. (2013). Trunk axial rotation in baseball pitching and batting. *Sports Biomechanics, 12(4)*, 324-333. https://doi.org/10.1080/14763141.2013.838693

Fortenbaugh, D., Fleisig, G.S., & Andrews, J.R. (2009). Baseball pitching biomechanics in relation to injury risk and performance. *Sports Health*, *1*(4), 314-320. https://doi.org/10.1177/1941738109338546

Huang, T., Wei, S., Jung-Chi, C., Hsu, M., & Chang, H. (2005). Isokinetic evaluation of shoulder internal and external rotators concentric strength and endurance in baseball players: Variations from pre-pubescence to adulthood. *Isokinetics and Exercise Science, 13(4)*, 237-241. https://doi: 10.3233/IES-2005-0207

Ishida, K., & Hirano, Y. (2004). Effects of non-throwing arm on trunk and throwing arm movements in baseball pitching. *International Journal of Sport and Health Science, 2*, 119-128. https://doi.org/10.5432/ijshs.2.119

Kibler, W.B. (1994). Clinical biomechanics of the elbow in tennis: Implications for evaluation and diagnosis. *Medicine and Science in Sports and Exercise*, *26*(10), 1203-1206.

Lawshe C.H. (1975). A quantitative approach to content validity. *Personnel Psychology, 28(4)*, 563-575.

MacWilliams, B.A., Choi, T., Perezous, M.K., Chao, E.Y., & McFarland, E.G. (1998). Characteristic ground-reaction forces in baseball pitching. *The American Journal of Sports Medicine*, *26*(1), 66-71. https://doi.org/10.1177/03635465980260012801

Magnusson, S.P., Gleim, G.W., & Nicholas, J.A. (1994). Shoulder weakness in professional baseball pitchers. *Medicine and Science in Sports and Exercise*, *26*(1), 5-9.

Matsuo, T., Escamilla, R.F., Fleisig, G.S., Barrentine, S.W., & Andrews, J.R. (2001). Comparison of kinematic and temporal parameters between different pitch velocity groups. *Journal of Applied Biomechanics, 17(1)*, 1-13. https://doi.org/10.1123/jab.17.1.1

McEvoy, K.P., & Newton, R.U. (1998). Baseball throwing speed and base running speed: The Effects of ballistic resistance training. *Journal of Strength and Conditioning Research, 12(4)*, 216-221.

McNally, M.P., Borstad, J.D., Oñate, J.A., & Chaudhari, A.M. (2015). Stride leg ground reaction forces predict throwing velocity in adult recreational baseball pitchers. *Journal of Strength and Conditioning Research*, *29*(10), 2708-2715. https://doi: 10.1519/JSC.0000000000000937

Newton, R.U., & McEvoy, K.I. (1994). Baseball throwing velocity: A comparison of medicine ball training and weight training. *Journal of Strength and Conditioning Research, 8(3)*, 198-203.

NSCA—National Strength and Conditioning Association. (2008). *Essentials of strength training and conditioning.* Champaign, IL: Human Kinetics.

Olsen, S.J. 2nd, Fleisig, G.S., Dun, S., Loftice, J., & Andrews, J.R. (2006). Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *The American Journal of Sports Medicine*, *34*(6), 905-912. https://doi.org/10.1177/0363546505284188

Oyama, S., Yu, B., Blackburn, J.T., Padua, D.A., Li, L., & Myers, J.B. (2013). Effect of excessive contralateral trunk tilt on pitching biomechanics and performance in high school baseball pitchers. *The American Journal of Sports Medicine*, *41*(10), 2430-2438. https://doi.org/10.1177/0363546513496547

Parsons, C., Sulaeman, J., Yates, M.C., & Hamermesh, D.S. (2011). Strike three: Discrimination, incentives, and evaluation. *The American Economic Review, 101(4)*, 1410-1435.

Perkin, D.G. (2014). *Five-plus tools: The past, present, and future of baseball through the eyes of a scout*. Sports Publishing.

Pocock, S.T. (1983). *Clinical trials, a practical approach*. Essex: John Wiley & Sons.

Popescue, M.G. (1975). Weight training and the velocity of a baseball. *Athletic Journal, 55(9)*, 74-106.

Pugh, S.F., Kovaleski, J.E., Heitman, R.J., & Pearsall, A. W. (2001). Upper and lower body strength in relation to underhand pitching speed by experienced and inexperienced pitchers. *Perceptual and Motor Skills, 93(3)*, 813-818. https://doi.org/10.2466/pms.2001.93.3.813

Raeder, C., Fernandez-Fernandez, J., & Ferrauti, A. (2015). Effects of six weeks of medicine ball training on throwing velocity, throwing precision, and isokinetic strength of shoulder rotators in female handball players. *Journal of Strength and Conditioning Research*, *29*(7), 1904-1914. https://doi: 10.1519/JSC.0000000000000847

Reiff, G.G. (1971). *What research tells the coach about baseball*. American Association for Health, Physical Education and Recreation.

Rodgers, M.M., & Whipple, R.H. (1990). Specificity of speed of exercise. *The Journal of Orthopaedic and Sports Physical Therapy*, *12*(2), 72-78. https://doi.org/10.2519/jospt.1990.12.2.72

Seroyer, S.T., Nho, S.J., Bach, B.R., Bush-Joseph, C.A., Nicholson, G.P., & Romeo, A.A. (2010). The kinetic chain in overhand pitching: Its potential role for performance enhancement and injury prevention. *Sports Health*, *2*(2), 135-146. https://doi.org/10.1177/1941738110362656

Spaniol, F.J. (2009). Baseball athletic test: A baseball-specific test battery. *Strength and Conditioning Journal, 31(2)*, 26-29. https://doi: 10.1519/SSC.0b013e31819d3af8

Stockbrugger, B.A., & Haennel, R.G. (2001). Validity and reliability of a medicine ball explosive power test. *Journal of Strength and Conditioning Research*, *15*(4), 431-438.

Stodden, D.F., Campbell, B.M., & Moyer, T.M. (2008). Comparison of trunk kinematics in trunk training exercises and throwing. *Journal of Strength and Conditioning Research*, *22*(1), 112-118. https://doi: 10.1519/JSC.0b013e31815f2a1e

Stodden, D.F., Fleisig, G.S., McLean, S.P., & Andrews, J.R. (2005). Relationship of biomechanical factors to baseball pitching velocity: Within pitcher variation. *Journal of Applied Biomechanics, 21(1)*, 44-56. https://doi.org/10.1123/jab.21.1.44

Stodden, D.F., Fleisig, G.S., McLean, S.P., Lyman, S.L., & Andrews, J.R. (2001). Relationship of pelvis and upper torso kinematics to pitched baseball velocity. *Journal of Applied Biomechanics, 17*, 164-172. https://doi.org/10.1123/jab.17.2.164

Taniyama, D., Matsuno, J., Yoshida, K., Pyle, B., & Nyland, J. (2021). Rotational medicine ball throw velocity relates to NCAA Division III college baseball player bat swing, batted baseball, and pitching velocity. *Journal of Strength and Conditioning Research*, *35*(12), 3414-3419. https://doi: 10.1519/JSC.0000000000004148

Toyoshima, S., Hoshikawa, T., Miyashita, M., & Oguri, T. (1974). Contribution of the body parts to throwing performance. In R.C. Nelson & C.A. Morehouse (Eds.), *Biomechanics IV.* International Series on Sport Sciences. London: Palgrave.

Werner, S.L., Suri, M., Guido, J.A. Jr, Meister, K., & Jones, D.G. (2008). Relationships between ball velocity and throwing mechanics in collegiate baseball pitchers. *Journal of Shoulder and Elbow Surgery*, *17*(6), 905-908. https://doi.org/10.1016/j.jse.2008.04.002

Wooden, M.J., Greenfield, B., Johanson, M., Litzelman, L., Mundrane, M., & Donatelli, R.A. (1992). Effects of strength training on throwing velocity and shoulder muscle performance in teenage baseball players. *The Journal of Orthopaedic and Sports Physical Therapy*, *15*(5), 223-228. https://www.jospt.org/doi/10.2519/jospt.1992.15.5.223

Yanagisawa, O., Miyanaga, Y., Shiraki, H., Shimojo, H., Mukai, N., Niitsu, M., & Itai, Y. (2003). The effects of various therapeutic measures on shoulder strength and muscle soreness after baseball pitching. *The Journal of Sports Medicine and Physical Fitness*, *43*(2), 189-201.

Received: March 20, 2023
Accepted: April 24, 2024
Published Online First: November 15, 2024

Correspondence to:
Zhigang Yang, Ph.D.
Handan Road 220, Shanghai, China
Email: yangzhigang@fudan.edu.cn
Phone: 13816045316

Acknowledgments

The authors express their gratitude to the coaches and participants for their participation in this study.

RESISTANCE TRAINING CARRIED OUT BEFORE PRACTICE COMPROMISES THE PERFORMANCE OF SEVERAL HIGH-VELOCITY TASKS IN SOCCER GOALKEEPERS

Danica Janicijevic[1,2,3], Jesualdo Cuevas-Aburto[3], Zhaoqian Li[4], and Amador García-Ramos[1,4]

[1]*Faculty of Sports Science, Ningbo University, Ningbo, China*
[2]*Research Academy of Human Biomechanics, The Affiliated Hospital of Medical School of Ningbo University, Ningbo University, Ningbo, China*
[3]*Department of Sports Sciences and Physical Conditioning, Faculty of Education, Universidad Católica de la Santísima Concepción, Concepción, Chile*
[4]*Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Spain*

Original scientific paper
DOI 10.26582/k.56.2.4

Abstract:

This study aimed to elucidate whether the performance of high-velocity soccer-related tasks is compromised immediately after completing squat-based resistance training sessions differing in the level of effort. Eleven young male soccer goalkeepers (age: 17.1±1.7 years) completed four testing sessions. The parallel back-squat one-repetition maximum (1RM) was determined in the first session. The remaining sessions were applied in a counterbalanced order and they consisted of the assessment of four high-velocity soccer-related tasks (countermovement jump [CMJ], horizontal jump, soccer kicking, and soccer throwing) at rest (*control protocol*) and immediately after completing four sets of the squat exercise against the 60%1RM until reaching a velocity loss of 15% (*low-effort protocol*) and 30% (*moderate-effort protocol*). The mean velocity of the fastest repetition did not differ between the protocols (≈ 0.80 $m \cdot s^{-1}$; p=.447), whereas the number of repetitions was greater for the moderate-effort (18.2±5.3 repetitions) compared to the low-effort (10.1±4.5 repetitions) protocol (p<.001). The protocols were ranked according to the magnitude of the dependent variables as follows: CMJ height (control > low-effort = moderate-effort), horizontal jump distance (control > low-effort > moderate-effort), kicked ball distance (low-effort = control = moderate-effort), and thrown ball distance (control = low-effort = moderate-effort). These results indicate that squat-based RT sessions compromise the performance of some high-velocity tasks (vertical and horizontal jumps) but not others (kicking and throwing), whereas a greater level of effort (i.e., velocity loss) only induced larger reductions in the performance of the horizontal jump distance.

Key words: *football, jump, kicking, squat, throwing, velocity-based training*

Introduction

Resistance training (RT) plays a relevant role in the training process of virtually any sport discipline (Kraemer, Ratamess, & French, 2002; Pareja-Blanco, Rodríguez-Rosell, Sánchez-Medina, & González-Badillo, 2014). There is strong evidence that RT-induced muscular strength adaptations are important both for enhancing performance during sport-specific actions and for reducing the prevalence of sports injuries (Lauersen, Bertelsen, & Andersen, 2014; Suchomel, Nimphius, & Stone, 2016). Soccer, recognised as the most popular and widely researched sport globally (Millet, Brocherie, & Burtscher, 2022), also has extensive scientific evidence supporting the positive effects of various RT programs on sport-specific task performance (Garcia-Ramos, Haff, Feriche, & Jaric, 2018; Silva, Nassis, & Rebelo, 2015). A systematic review conducted by Silva et al. (2015) concluded that strength training contributes to improving both physiological and physical measures associated with high-level performance of soccer players. In addition, a meta-analysis revealed that the implementation of RT in addition to regular soccer training significantly enhances the performance of high-velocity soccer-related tasks in soccer players

(García-Ramos, et al., 2018). Maximal dynamic strength (e.g., squat one-repetition maximum [1RM]) has also been positively correlated with the performance of relevant high-velocity actions in soccer such as jump height and sprint time (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). Therefore, taking into account the scientific evidence, it is not surprising that RT plays a major role in the contemporary training routine of soccer players.

The squat is a basic exercise in most RT programs that aims to develop the maximal strength and power capabilities of lower-body muscles (Cormie, McCaulley, & McBride, 2007; Nigro & Bartolomei, 2020; Wirth, et al., 2016). Therefore, it is not surprising that the squat exercise and its ballistic variant (jump squat) have been extensively used in scientific research to develop the performance of high-velocity soccer-related tasks in soccer players (e.g., jumping, sprinting, changing of direction, or kicking) (Coratella, et al., 2018; González-Badillo, et al., 2015; Styles, Matthews, & Comfort, 2016). Several studies have revealed that squat-based RT programs performed against light-moderate loads (50-60%1RM) are effective to improve execution of sport-specific tasks (e.g., jumping and sprinting) in soccer players (Galiano, Pareja-Blanco, de Mora, & Villarreal, 2022; Pareja-Blanco, Sánchez-Medina, Suárez-Arrones, & González-Badillo, 2017; Rodríguez-Rosell, et al., 2021). An important characteristic of the aforementioned studies is that the lifting phase of the repetitions was always executed at maximal intended velocity. Intended lifting velocity is an important training variable as it has been repeatedly demonstrated that deliberately lifting at submaximal velocities during RT compromises adaptations directed towards improving athletic performance (González-Badillo, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & Pareja-Blanco, 2014; Pareja-Blanco, et al., 2014). The RT-induced muscular strength adaptations are also influenced by the fatigue induced in the training sets; low to moderate velocity losses promote greater gains in sport-specific tasks (e.g., jumping and sprinting) and higher velocity losses are more suitable for inducing muscle hypertrophy (Jukic, et al., 2023). Therefore, soccer players are generally instructed to execute the squat exercise at maximal intended velocity and to stop the sets after a few repetitions have been completed to mitigate the velocity loss (i.e., fatigue).

The tight schedule of soccer players promotes the idea that RT sessions should be frequently carried out immediately before specific soccer practice. This can be problematic as the immediate effect of RT is a reduction in the ability to apply force (i.e., fatigue) (Linnanio, Häkkinen, & Komi, 1998; Sabag, et al., 2021). High fatigue is expected to induce a deterioration in the ability to perform soccer-specific technical and tactical actions and also to increase the likelihood of contracting injuries during specific soccer practice (Small, McNaughton, Greig, & Lovell, 2010; Smith, et al., 2018). Therefore, to mitigate the stress and fatigue induced by RT, soccer players rarely lift heavy loads (> 75%1RM) and also restrict the level of effort by not performing sets to failure (Franco-Márquez, et al., 2015; González-Badillo, et al., 2015; Pareja-Blanco, et al., 2017; Styles, et al., 2016). Of note is that the scientific literature related to soccer and RT has been predominantly focused on outfield players (García-Ramos, et al., 2018; González-Badillo, et al., 2015; Harries, Lubans, & Callister 2012). However, goalkeepers, which is an extremely important position in soccer, are also expected to benefit from RT as they need to perform a number of high-velocity actions such as jumping, ball kicking and ball throwing to defend their goal (Ziv & Lidor, 2011). These demands differ significantly from those of field players, who often focus more on endurance and sustained mechanical performance. Consequently, the strength and conditioning needs of goalkeepers include exercises that enhance quick force production in both upper and lower body movements (Perez-Arroniz, Calleja-González, Zabala-Lili, & Zubillaga 2023). Given these distinct requirements, the present study specifically examines how RT protocols impact high-velocity tasks pertinent to goalkeeping performance, providing a focused insight into optimizing goalkeeper-specific training.

To address the discussed issues, we assessed the performance of soccer goalkeepers during high-velocity soccer-related tasks (countermovement jump [CMJ], horizontal jump, soccer ball kicking, and soccer ball throwing) at rest (control condition) and immediately after completing multiple sets of the squat exercise until reaching a velocity loss of 15% (low-effort condition) and 30% (moderate-effort condition). Specifically, the aims of the present study were (i) to compare several training variables (e.g., number of repetitions performed and mean velocity of the fastest repetition of the sets) between two squat-based RT sessions differing in the level of effort (low-effort [15% velocity loss] vs. moderate-effort [30% velocity loss]), and (ii) to elucidate whether the performance of high-velocity soccer-related tasks was compromised in soccer goalkeepers immediately after completing squat-based RT sessions at low (15% velocity loss) and moderate (30% velocity loss) levels of effort. We hypothesised that (i) goalkeepers would perform more repetitions after the moderate-effort training protocol, while the mean velocity of the fastest repetition of the set would be greater from the second set on for the low-effort training protocol, and (ii) the performance of high-velocity soccer-related tasks would be deteriorated compared to the control condition following the moderate-effort training protocol but not after the low-effort training protocol.

Method

Participants

Eleven young male soccer goalkeepers (age: 17.1±1.7 years [range: 15-20 years], body mass: 76.1±6.3 kg, height: 1.81±0.05 m) volunteered to participate in this study. All goalkeepers were members of three youth soccer teams from the region of Biobío (Chile) and belonged to the lower divisions of professional football teams. Goalkeepers were tested during the in-season period. A typical week during the in-season period consisted of four soccer practices, two RT sessions, and a competitive match. All subjects had previous experience in the squat exercise and also in the high-velocity tasks evaluated in our study (CMJ, horizontal jump, soccer ball kicking, and soccer ball throwing). All subjects were informed of the study procedures and they or their legal guardians signed a written informed consent form prior to initiating the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of the University of Granada (Spain).

Study design

A crossover study design was used to elucidate whether the performance of high-velocity soccer-related tasks was compromised in soccer goalkeepers immediately after completing squat-based RT sessions at different levels of effort. Participants completed four testing sessions, at the same time of the day, each separated by seven days. The first session was used to determine the parallel back-squat one-repetition maximum (1RM) and to familiarise participants with the execution of consecutive squat repetitions at the maximal intended velocity. The three remaining experimental sessions were performed in a randomised and counterbalanced order. Four high-velocity soccer-related tasks (CMJ, horizontal jump, soccer ball kicking, and soccer ball throwing) were evaluated in each session immediately after completing one of the following protocols: (i) *control* – *no* RT session was performed; (ii) *low-effort* – four sets of the parallel back-squat exercise with three minutes of inter-set rest at the maximal intended velocity against the 60%1RM load until reaching a mean velocity (MV) loss of 15%; and (iii) *moderate-effort* – four sets of the parallel back-squat exercise with three minutes of inter-set rest at the maximal intended velocity against the 60%1RM load until reaching a MV loss of 30%. Therefore, the two training protocols only differed in the level of effort as higher velocity losses during RT have been associated with greater mechanical and metabolic markers of fatigue (Sánchez-Medina & González-Badillo, 2011).

Procedures

Preliminary session (session 1)

Body mass (Tanita BC 418 segmental; Tanita Corp, Tokyo, Japan) and height (Seca 202; Seca Ltd, Hamburg, Germany) were measured at the beginning of the testing session. Afterwards, a standardised warm-up was completed: five minutes of jogging, lower-body joint mobilization exercises, and five repetitions of the parallel back-squat exercise with an absolute load of 20 kg. Thereafter, participants performed an incremental loading test to estimate the back-squat 1RM. The initial load was set to 20 kg and was progressively increased by 15 kg until the MV was lower than 0.60 $m \cdot s^{-1}$. Two trials were performed with each load. A passive rest period of three minutes was implemented between successive loads.

The parallel back-squat exercise was always performed in a Smith machine (Ffittech, Taipei, China). The feet were shoulder-width apart and the barbell remained in contact with the upper back ("high bar position"). From the initial position, participants were required to descend in a continuous motion until their thighs were parallel to the floor and immediately after to perform the lifting phase at the maximal intended velocity without jumping off the ground. The MV was recorded with a linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) that was vertically attached to the barbell of the Smith machine and sampled the velocity-time data at a frequency of 1,000 Hz. Participants received MV feedback immediately after completing each repetition, and they were encouraged to perform all repetitions at the maximal intended velocity. The trial with greater MV of each load was used to determine the individualised load-MV relationships by means of linear regression models. The absolute load linked to a MV of 0.33 $m \cdot s^{-1}$ obtained from the individualised load-velocity relationships was considered to be the parallel back-squat 1RM (95.3±25.4 kg [range: 64-136 kg]). The 60% of this 1RM value (59.5±15.9 kg [range: 40-85 kg]) was used in the low-effort and moderate-effort training protocols.

Experimental sessions (session 2-4)

The three experimental sessions were performed in a randomised and counterbalanced order. The experimental sessions only differed in the training protocol followed: (i) *control* – no RT session was performed; (ii) *low-effort* – four sets of the parallel back-squat exercise with three minutes of inter-set rest at maximal intended velocity against the 60% of the 1RM load determined in session one until reaching a mean velocity (MV) loss of 15%; and (iii) *moderate-effort* – four sets of the parallel back-squat exercise with three minutes of inter-set rest at maximal intended velocity against the 60% of the 1RM load determined in session one until reaching a MV loss of 30%. The warm-up preceding the low- and moderate-effort training protocols consisted of five minutes of jogging, lower-body joint mobilization exercises, and one set of 10, five, and two repetitions of the parallel back-squat exercise against the 30, 50, and 70%1RM, respectively. After warming-up, participants rested for three minutes and then they performed the four sets of the respective training protocol. Subjects were encouraged to perform all repetitions at the maximal intended velocity and received MV feedback immediately after completing each repetition.

The testing protocols of the high-velocity soccer-related tasks were initiated 20 minutes after completing the last set of the low- and moderate-effort training protocols. The testing protocol was initiated with a standardised warm-up consisting of five minutes each of jogging and joint mobilization exercises. A specific warm-up was performed immediately before each task consisting of three submaximal trials with progressive effort. Participants performed three trials of each task separated by 30 seconds. A rest period of one minute was implemented between different tasks. The four tasks were performed in a randomised order but the same order was followed by individual participants in the three experimental sessions. The characteristics of the four high-velocity soccer-related tasks are provided below:

- *Countermovement jump (CMJ):* Subjects began standing in a comfortable bilateral stance with each leg fully extended, the feet positioned hip-width apart, and the hands placed on the hips. Subsequently, subjects were instructed to jump as high as possible after performing a countermovement to a self-selected depth. CMJ height was estimated from flight time using an infrared platform (Optojump, Microgate, Italy).
- *Horizontal jump:* Subjects began standing in a comfortable bilateral stance with each leg fully extended, the feet positioned hip-width apart, and the hands placed on the hips. Subsequently, participants were instructed to jump forward as far as possible and land on both legs simultaneously after performing a countermovement to a self-selected depth. Subjects had to keep their hands on the hips throughout the whole movement. Jump distance was recorded with a tape measure from the start line to the heel of the rearmost foot.
- *Soccer ball kicking:* Participants were instructed to kick a soccer ball as far as possible in a straight line after performing a free approach run simulating a goal kick. The distance to the first bounce of the ball was quantified with a tape measure. Two trained observers were positioned close to the testing area to visually confirm the first bounce of the ball.
- *Soccer ball throwing:* Goalkeepers used the side hook technique with the dominant hand as it was the most used by most of them. Participants were allowed to use a free approach run until the throwing line. The distance to the first bounce of the ball was quantified with a tape measure. Two trained observers were positioned close to the testing area to visually confirm the first bounce of the ball.

Statistical analyses

Descriptive data are presented as means and standard deviations. The normal distribution of the data and the homogeneity of the variances were confirmed by the Shapiro-Wilk and Levene's tests, respectively ($p>.05$). The two trials with higher performance of each test were used to assess the intra-day reliability by calculating the coefficient of variation (CV (%) = standard error of measurement / participants' mean score × 100) and intraclass correlation coefficient (ICC; model 3.1) with their corresponding 95% confidence intervals. Acceptable and high reliability thresholds for the CV were set at ≤ 10 and ≤ 5%, respectively (James, Roberts, Haff, Kelly, & Beckman, 2017). In addition, ICC values were interpreted according to the following guideline: poor [ICC<.50], moderate [ICC=.50-.75], good [ICC=.75-.90], and excellent [ICC>.90] reliability (Koo & Li, 2016). A two-way repeated measures analysis of variance (ANOVA) (training protocol [low-effort vs moderate-effort]) × set number [set 1 vs set 2 vs set 3 vs set 4]) with Bonferroni *post-hoc* corrections was applied to the different training variables (number of repetitions performed, mean velocity of the fastest repetition, and mean velocity of the last repetition). In addition, a one-way repeated measures ANOVA (training protocol: control vs low-effort vs moderate-effort) was used to compare the different dependent variables (CMJ height, horizontal jump distance, kicked ball distance, and thrown ball distance). The final database can be downloaded through the following link: https://acortar.link/fgpTS1. Reliability assessments were performed by means of a custom Excel spreadsheet (Hopkins, 2000), while other statistical analyses were performed using SPSS software version 25.0 (SPSS Inc., Chicago, IL, USA). Statistical significance was set at an alpha level of 0.05.

Results

The descriptive values of the training variables are provided in Table 1. The number of repetitions completed was higher for the moderate-effort training protocol (18.2±5.3 repetitions) compared to the low-effort training protocol (10.1±4.5 repetitions) (p<.001), and they tended to decrease from the third set of the training session (set 1: 15.4±6.5 repetitions; set 2: 15.6±6.4 repetitions; set 3: 13.4±6.3 repetitions; set 4: 12.2±6.1 repetitions) (p=.002). The mean velocity of the fastest repetition did not differ between the training protocols (p=.447) or sets (p=.582). Finally, the mean velocity of the last repetition was lower for the moderate-effort training protocol (0.55±0.04 $m \cdot s^{-1}$) compared to the low-effort training protocol (0.68±0.03 $m \cdot s^{-1}$) (p<.001), but the main effect of set did not reach statistical significance (p=.778).

The four dependent variables were obtained with a high reliability (CV range=1.53-4.98%; ICC range=.83-.99) (Table 2). CMJ height and horizontal jump distance were significantly impaired after the low-effort (Δ = -4.40 and -1.43%, respectively) and moderate-effort (Δ = -5.44 and -4.45%, respectively) training protocols compared to the control condition (Figure 1). CMJ height was comparable following the low-effort and moderate-effort training protocols (p=.366, Δ = 1.09%), but horizontal jump distance was greater after the low-effort training protocol compared to the moderate-effort training protocol (p=.023, Δ = 3.06%). No significant differences between the three training protocols were obtained for kicked ball distance (p=.221) or thrown ball distance (p=.935).

Discussion and conclusion

This study was designed to explore whether completing a squat-based RT session could acutely reduce the performance of certain high-velocity soccer-related tasks in soccer goalkeepers and to determine whether the potential interference effect could be modulated by the level of effort induced by the training sets. The two training protocols differed in the number of repetitions performed (low-effort < moderate-effort) and mean velocity of the last repetition of the set (low-effort > moderate-effort), but they did not differ in the mean velocity of the fastest repetition of the set (low-effort = moderate-effort). The comparison between the training protocols for the performance of the four high-velocity soccer-specific tasks is summarised as follows: CMJ height (control > low-effort = moderate-effort), horizontal jump distance (control > low-effort > moderate-effort), kicked ball distance (low-effort = control = moderate-effort), and thrown ball distance (control = low-effort = moderate-effort). These results indi-

Table 1. Comparison of the training variables between the low- and moderate-effort training protocols

Variable	Training protocol	Set number				ANOVA		
		Set 1	Set 2	Set 3	Set 4	Protocol	Set	Interaction
Number of repetitions	Low-effort	10.9 (3.2)	11.7 (5.5)	9.0 (4.4)	8.7 (4.6)	F = 31.0 *p* < 0.001	F = 6.3 *p* = 0.002	F = 0.5 *p* = 0.697
	Moderate-effort	19.9 (5.9)*	19.4 (4.7)*	17.7 (4.6)*	15.6 (5.6)*			
$MV_{fastest}$ ($m \cdot s^{-1}$)	Low-effort	0.82 (0.02)	0.79 (0.03)	0.80 (0.04)	0.78 (0.06)	F = 0.6 *p* = 0.447	F = 0.7 *p* = 0.582	F = 2.2 *p* = 0.109
	Moderate-effort	0.78 (0.06)*	0.80 (0.06)	0.81 (0.06)	0.79 (0.06)			
MV_{last} ($m \cdot s^{-1}$)	Low-effort	0.69 (0.03)	0.67 (0.04	0.68 (0.03	0.69 (0.02)	F = 126.8 *p* < 0.001	F = 0.4 *p* = 0.778	F = 2.0 *p* = 0.140
	Moderate-effort	0.56 (0.05)*	0.56 (0.03)*	0.56 (0.06)*	0.54 (0.03)*			

Note. Data presented as means (standard deviation). $MV_{fastest}$, mean velocity of the fastest repetition of the set; last, mean velocity of the last repetition of the set. *, significantly different than low-effort.

Table 2. Reliability and statistical comparisons between the three training protocols of the four high-velocity soccer-related tasks

Variable	Reliability		Training protocol			ANOVA
	CV (%) (95% CI)	ICC (95% CI)	Control	Low-effort	Moderate-effort	
CMJ height (cm)	1.91 (1.34, 3.36)	0.99 (0.97, 1.00)	37.9 (7.2)	36.2 (6.6)^a	35.8 (6.1)^a	F = 7.8 *p* = 0.003
Horizontal jump distance (cm)	1.53 (1.07, 2.69)	0.83 (0.49, 0.95)	219.7 (7.5)	216.6 (7.5)^a	209.9 (13.4)^{a,b}	F = 10.3 *p* = 0.001
Kicked ball distance (m)	4.98 (3.48, 8.73)	0.90 (0.66, 0.97)	44.7 (5.9)	45.4 (6.8)	43.7 (6.2)	F = 1.6 *p* = 0.221
Thrown ball distance (m)	3.33 (2.33, 5.84)	0.94 (0.80, 0.98)	30.2 (4.3)	29.9 (3.6)	29.9 (3.2)	F = 0.1 *p* = 0.935

Note. Data presented as means (standard deviation). CMJ, countermovement jump; CV, coefficient of variation; ICC, intraclass correlation coefficient; CI, confidence interval; ANOVA, analysis of variance. ^{a}, significantly lower than control; ^{b}, significantly lower than the low-effort training protocol.

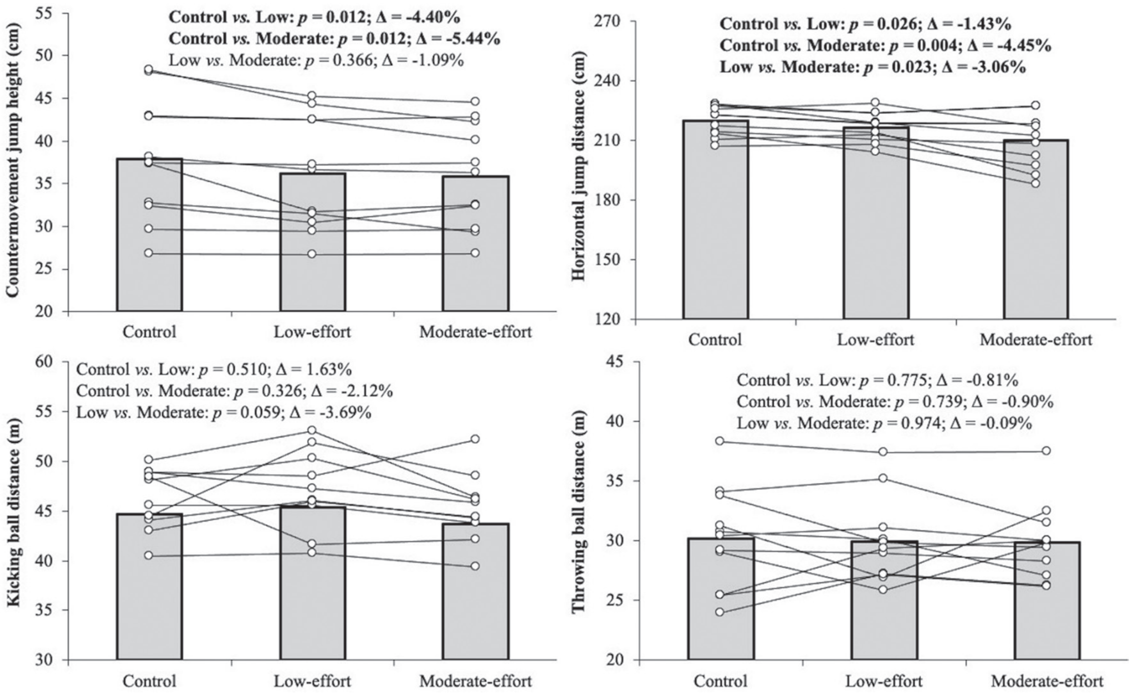


Figure 1. Individual values and comparisons of countermovement jump height (upper-left panel), horizontal jump distance (upper-right panel), kicking distance (lower-left panel), and throwing distance (lower-right panel) between the control, low-effort, and moderate-effort training protocols.

cate that a squat-based RT session compromises the performance of some high-velocity tasks (CMJ height and horizontal jump distance) but not others (kicked and thrown ball distance), whereas the increase in the level of effort (i.e., from low to moderate velocity loss) is not always associated with greater reductions in the performance of high-velocity soccer-related tasks.

Existing research has paid attention to the acute effects of different velocity loss thresholds on various neuromuscular, metabolic and perceptual markers of fatigue (Jukic, et al., 2023). The reduction in CMJ height was accentuated with the use of greater velocity loss thresholds (Weakley, et al., 2020). Similarly, the differential rating of perceived exertion and some biochemical plasma indicators (e.g., blood lactate and creatine kinase concentration) were higher for increasing velocity loss thresholds (Pareja-Blanco, et al., 2020; Weakley, et al., 2020). In line with previous research and our hypothesis, the final set velocity was lower for the moderate-effort training protocol, and this promoted that the number of repetitions completed with this protocol to be higher compared to the low-effort training protocol. An interesting finding is that, regardless of the training protocol, the number of repetitions completed decreased progressively with an increasing number of sets, but the velocity of the fastest repetition was not affected by the training protocol or the set number. These results suggest that during training both protocols affected more the ability to maintain high velocity outputs (i.e., maximal velocity maintenance capacity) than maximal velocity production capacity.

The CMJ is not only a high-velocity task related to soccer performance, but also a task commonly used for training, monitoring, and testing purposes (Loturco, et al., 2015; Seitz, Mina, & Haff, 2016; Syuhadah, et al., 2022; Weakley, et al., 2019). Ballistic training, which frequently includes the CMJ exercise, has been shown to be effective in improving a number of physical attributes such as agility and maximal power output (Makaruk & Sacewicz, 2010; Syuhadah, et al., 2022). CMJ height performance is also positively correlated with lower extremity maximal strength and power capabilities, and its ease of implementation is responsible for its high popularity as a field test (Linthorne, 2021; Nuzzo, Mcbride, Cormie, Mccaulley, 2008). Of even more importance for our study is that the decrement in CMJ height has been shown to be a powerful indicator of neuromuscular fatigue (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015). For example, the magnitude of velocity loss incurred during a squat-based RT session performed with a load equivalent to a MV of 0.70 $m \cdot s^{-1}$ was directly related with the acute decrement in CMJ height (Wirth, et al., 2016). Our results are only partially in agreement with previous findings. As hypothesised, CMJ height significantly decreased after both RT protocols, but the decrement was comparable for the low- and moderate-effort training protocols despite those participants performed on average eight repetitions more during the moderate-effort protocol. The use of a lighter load in our study (MV ≈ 0.80 $m \cdot s^{-1}$) and the completion of a high number of repetitions in both protocols (> 10 repetitions per set) might be responsible for the comparable decrements in CMJ height following both training protocols.

Horizontal jump distance is another simple field test commonly used to assess horizontal force production capacity, and it is positively correlated with sprint performance (Lin, Shen, Zhang, Zhou, & Guo, 2023). Despite that the orientation of force application with respect to the squat exercise is obviously less specific for the horizontal jump than for the CMJ, horizontal jump distance presented a higher sensitivity to detect the different degrees of fatigue induced by the squat-based RT protocols. Namely, the greatest and lowest horizontal jump distance were obtained after the control and moderate-effort protocols, respectively. Therefore, while CMJ height was not able to detect differences between the low- and moderate-effort training protocols, horizontal jump distance was greater for the low-effort training protocol. These results reinforce the use of horizontal jump distance as an indicator of lower-body neuromuscular fatigue. Taken together the data for vertical and horizontal jumps, it seems evident that after a RT session consisting of multiple sets of more than 10 repetitions of the squat exercise, there is a deterioration in the performance of global ballistic tasks such as the CMJ and horizontal jump. Therefore, when a squat-based RT session is programmed immediately before a soccer-specific practice, it may be preferable to lift heavier loads and reduce the number of repetitions completed per set, or if the load is maintained to complete a lower number of sets (< 4) or reduce the velocity loss below the 15% threshold.

Unlike vertical and horizontal jumps, our results showed that ball-kicking performance was not affected by any of the RT protocols. This may be because the muscles involved in kicking were not as fatigued by the squat exercises used in the protocols. In this sense, Young and Rath (2011) reported that the concentric contractions of hip flexors and knee extensors explain a significant amount of the variance in soccer ball-kicking velocity. Therefore, it is plausible to infer that these muscle functions are not greatly affected by the squat exercise used in the training protocols (Torreblanca-Martinez, Otero-Saborido, & Gonzalez-Jurado, 2017). Previous studies have also revealed that soccer kicking performance is not affected by simulated soccer matches (Ferraz, van den Tillaar, Pereira, Marques 2019; Russell, Benton, & Kingsley, 2011). Similarly, thrown ball distance was not affected by any of the RT protocols. This result was expected since throwing ball performance is mainly determined by the impulse developed by upper-body muscles (Pontaga & Zidens, 2014), and upper-body muscles were not involved in the RT protocols.

The main novelty of this study is that we examined the acute effects of different RT protocols on high-velocity tasks relevant to performance of soccer goalkeepers rather than on more generic markers of metabolic and mechanical fatigue. Although we are aware that other specific actions could have been analysed (e.g., repetitive jumps), we limited our analysis to tasks that are not expected to induce high amounts of fatigue. Finally, the main limitation of this study is that the results can only be extrapolated to the squat exercise and the use of similar RT configurations, being necessary that future studies explore the most effective RT configurations with potential to improve strength performance without inducing an acute decline in the performance of soccer-specific high-velocity tasks.

In conclusion, squat-based RT sessions performed against a moderate load (≈ 60%1RM) compromise the performance of some generic high-velocity tasks (vertical and horizontal jumps) but not the performance of ball-dealing tasks (kicking and throwing). A greater level of effort (i.e., velocity loss) was only associated with larger reductions in the performance of the horizonal jump. Therefore, soccer goalkeepers are advised not to use any of the RT configurations implemented in this study if they want to maintain maximal performance in high-velocity tasks during soccer practice.

References

Coratella, G., Beato, M., Milanese, C., Longo, S., Limonta, E., Rampichini, S., Ce, E., Bisconti, A. v., Schena, F., & Esposito, F. (2018). Specific adaptations in performance and muscle architecture after weighted jumpsquat vs. body mass squat jump training in recreational soccer players. *Journal of Strength and Conditioning Research*, *32*(4), 921-929. https://doi.org/10.1519/JSC.0000000000002463

Cormie, P., McCaulley, G.O., & McBride, J.M. (2007). Power versus strength-power jump squat training: Influence on the load-power relationship. *Medicine and Science in Sports and Exercise*, *39*(6), 996-1003. https://doi.org/10.1097/MSS.0B013E3180408E0C

Ferraz, R.M.P., van den Tillaar, R., Pereira, A., & Marques, M.C. (2019). The effect of fatigue and duration knowledge of exercise on kicking performance in soccer players. *Journal of Sport and Health Science*, *8*(6), 567-573. https://doi.org/10.1016/j.jshs.2016.02.001

Franco-Márquez, F., Rodríguez-Rosell, D., González-Suárez, J.M., Pareja-Blanco, F., Mora-Custodio, R., Yañez-García, J.M., & González-Badillo, J.J. (2015). Effects of combined resistance training and plyometrics on physical performance in young soccer players. *International Journal of Sports Medicine*, *36*(11), 906-914. https://doi.org/10.1055/S-0035-1548890/ID/R4636-0029

Galiano, C., Pareja-Blanco, F., de Mora, J.H., & de Villarreal, E.S. (2022). Low-velocity loss induces similar strength gains to moderate-velocity loss during resistance training. *Journal of Strength and Conditioning Research*, *36*(2), 340-345. https://doi.org/10.1519/JSC.0000000000003487

García-Ramos, A., Haff, G.G., Feriche, B., & Jaric, S. (2018). Effects of different conditioning programmes on the performance of high-velocity soccer-related tasks: Systematic review and meta-analysis of controlled trials. *International Journal of Sports Science and Coaching*, *13*(1), 129-151. https://doi.org/10.1177/1747954117711096

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. *International Journal of Sports Physiology and Performance*, *10*(1), 84-92. https://doi.org/10.1123/ijspp.2013-0413.

González-Badillo, J.J., Pareja-Blanco, F., Rodríguez-Rosell, D., Abad-Herencia, J.L., del Ojo-López, J.J., & Sánchez-Medina, L. (2015). Effects of velocity-based resistance training on young soccer players of different ages. *Journal of Strength and Conditioning Research*, *29*(5), 1329-1338. https://doi.org/10.1519/JSC.0000000000000764

González-Badillo, J.J., Rodríguez-Rosell, D., Sánchez-Medina, L., Gorostiaga, E.M., & Pareja-Blanco, F. (2014). Maximal intended velocity training induces greater gains in bench press performance than deliberately slower half-velocity training. *European Journal of Sport Science, 14*(8), 772-781. https://doi.org/10.1080/17461391.2014.905987

Harries, S.K., Lubans, D.R., & Callister, R. (2012). Resistance training to improve power and sports performance in adolescent athletes: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, *15*(6), 532-540. https://doi.org/10.1016/J.JSAMS.2012.02.005

Hopkins, W. (2000). *Calculations for reliability (Excel spreadsheet).* A New View of Statistics.

James, L.P., Roberts, L.A., Haff, G.G., Kelly, V.G., & Beckman, E.M. (2017). Validity and reliability of a portable isometric mid-thigh clean pull. *Journal of Strength and Conditioning Research*, *31*(5), 1378-1386. https://doi.org/10.1519/JSC.0000000000001201

Jukic, I., Castilla, A.P., Ramos, A.G., van Hooren, B., McGuigan, M.R., & Helms, E.R. (2023). The acute and chronic effects of implementing velocity loss thresholds during resistance training: A systematic review, meta-analysis, and critical evaluation of the literature. *Sports Medicine*, 53(1), 177-214. https://doi.org/10.1007/S40279-022-01754-4

Koo, T.K., & Li, M.Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Kraemer, W.J., Ratamess, N.A., & French, D.N. (2002). Resistance training for health and performance. *Current Sports Medicine Reports*, *1*(3), 165-171. https://doi.org/10.1007/S11932-002-0017-7

Lauersen, J.B., Bertelsen, D.M., & Andersen, L.B. (2014). The effectiveness of exercise interventions to prevent sports injuries: A systematic review and meta-analysis of randomised controlled trials. *British Journal of Sports Medicine*, *48*(11), 871-877. https://doi.org/10.1136/BJSPORTS-2013-092538

Lin, J., Shen, J., Zhang, J., Zhou, A., & Guo, W. (2023). Correlations between horizontal jump and sprint acceleration and maximal speed performance: A systematic review and meta-analysis. *PeerJ*, *11*, e14650. https://doi.org/10.7717/PEERJ.14650

Linnanio, V., Häkkinen, K., & Komi, P.V. (1998). Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *European Journal of Applied Physiology and Occupational Physiology*, *77*(1-2), 176-181. https://doi.org/10.1007/S004210050317/METRICS

Linthorne, N.P. (2021). The correlation between jump height and mechanical power in a countermovement jump is artificially inflated. *Sports Biomechanics*, *20*(1), 3-21. https://doi.org/10.1080/14763141.2020.1721737

Loturco, I., Pereira, L.A., Cal Abad, C.C., D'Angelo, R.A., Fernandes, V., Kitamura, K., Kobal, R., & Nakamura, F.Y. (2015). Vertical and horizontal jump tests are strongly associated with competitive performance in 100-m dash events. *Journal of Strength and Conditioning Research*, *29*(7), 1966-1971. https://doi.org/10.1519/JSC.0000000000000849

Makaruk, H., & Sacewicz, T. (2010). Effects of plyometric training on maximal power output and jumping ability. *Human Movement*, *11*(1), 17-22. https://doi.org/10.2478/V10038-010-0007-1

Millet, G.P., Brocherie, F., & Burtscher, J. (2022). Why soccer is the most attractive sport in sport sciences? *Medicine and Science in Sports and Exercise*, *54*(9S), 57. https://doi.org/10.1249/01.mss.0000875736.23710.84

Nigro, F., & Bartolomei, S. (2020). A comparison between the squat and the deadlift for lower body strength and power training. *Journal of Human Kinetics*, *73*(1), 145-152. https://doi.org/10.2478/HUKIN-2019-0139

Nuzzo, J.L., Mcbride, J.M., Cormie, P., & Mccaulley, G.O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research*, *22*(3), 699-707. https://doi.org/10.1519/JSC.0B013E31816D5EDA

Pareja-Blanco, F., Rodríguez-Rosell, D., Aagaard, P., Sánchez-Medina, L., Ribas-Serna, J., Mora-Custodio, R., Otero-Esquina, C., Yáñez-García, J.M., & González-Badillo, J.J. (2020). Time course of recovery from resistance exercise with different set configurations. *Journal of Strength and Conditioning Research*, *34*(10), 2867-2876. https://doi.org/10.1519/JSC.0000000000002756

Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Gorostiaga, E.M., & González-Badillo, J.J. (2014). Effect of movement velocity during resistance training on neuromuscular performance. *International Journal of Sports Medicine*, *35*(11), 916-924. https://doi.org/10.1055/S-0033-1363985/ID/R3832-0040

Pareja-Blanco, F., Sánchez-Medina, L., Suárez-Arrones, L., & González-Badillo, J.J. (2017). Effects of velocity loss during resistance training on performance in professional soccer players. *International Journal of Sports Physiology and Performance*, *12*(4), 512-519. https://doi.org/10.1123/IJSPP.2016-0170

Perez-Arroniz, M., Calleja-González, J., Zabala-Lili, J., & Zubillaga, A. (2023). The soccer goalkeeper profile: bibliographic review. *The Physician and Sportsmedicine*, *51*(3), 193-202. https://doi.org/10.1080/00913847.2022.2040889

Pontaga, I., & Zidens, J. (2014). Shoulder rotator muscle dynamometry characteristics: Side asymmetry and correlations with ball-throwing speed in adolescent handball players. *Journal of Human Kinetics*, *42*(1), 41-50. https://doi.org/10.2478/hukin-2014-0059

Rodríguez-Rosell, D., Yáñez-García, J.M., Mora-Custodio, R., Sánchez-Medina, L., Ribas-Serna, J., & González-Badillo, J.J. (2021). Effect of velocity loss during squat training on neuromuscular performance. *Scandinavian Journal of Medicine and Science in Sports*, *31*(8), 1621-1635. https://doi.org/10.1111/SMS.13967

Russell, M., Benton, D., & Kingsley, M. (2011). The effects of fatigue on soccer skills performed during a soccer match simulation. *International Journal of Sports Physiology and Performance*, *6*(2), 221-233. https://doi.org/10.1123/ijspp.6.2.221

Sabag, A., Lovell, R., Walsh, N.P., Grantham, N., Lacome, M., & Buchheit, M. (2021). Upper-body resistance training following soccer match play: Compatible, complementary, or contraindicated? *International Journal of Sports Physiology and Performance*, *16*(2), 165-175. https://doi.org/10.1123/IJSPP.2020-0762

Sánchez-Medina, L., & González-Badillo, J.J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and Science in Sports and Exercise*, *43*(9), 1725-1734. https://doi.org/10.1249/MSS.0B013E318213F880

Seitz, L.B., Mina, M.A., & Haff, G.G. (2016). Postactivation potentiation of horizontal jump performance across multiple sets of a contrast protocol. *Journal of Strength and Conditioning Research*, *30*(10), 2733-2740. https://doi.org/10.1519/JSC.0000000000001383

Silva, J.R., Nassis, G.P., & Rebelo, A. (2015). Strength training in soccer with a specific focus on highly trained players. *Sports Medicine—Open*, *1*(1), 17. https://doi.org/10.1186/S40798-015-0006-Z

Small, K., McNaughton, L., Greig, M., & Lovell, R. (2010). The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. *Journal of Science and Medicine in Sport*, *13*(1), 120-125. https://doi.org/10.1016/J.JSAMS.2008.08.005

Smith, M.R., Thompson, C., Marcora, S.M., Skorski, S., Meyer, T., & Coutts, A.J. (2018). Mental fatigue and soccer: Current knowledge and future directions. *Sports Medicine*, *48*(7), 1525-1532. https://doi.org/10.1007/S40279-018-0908-2/FIGURES/1

Styles, W.J., Matthews, M.J., & Comfort, P. (2016). Effects of strength training on squat and sprint performance in soccer players. *Journal of Strength and Conditioning Research*, *30*(6), 1534-1539. https://doi.org/10.1519/JSC.0000000000001243

Suchomel, T.J., Nimphius, S., & Stone, M.H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine*, *46*(10), 1419-1449. https://doi.org/10.1007/S40279-016-0486-0

Syuhadah, S.N., Sabadri, M., Sufyan, M., Zaki, M., Tun, B., & Razak Jengka, A. (2022). Effects of six weeks depth jump and countermovement jump training on agility performance among netball players. *Fitness, Performance and Health Journal*, *1*(1), 18-23. https://doi.org/10.53797/FPHJ.V1I1.3.2022

Torreblanca-Martinez, V., Otero-Saborido, F.M., & Gonzalez-Jurado, J.A. (2017). Effects of muscle fatigue induced by countermovement jumps on efficacy parameters of instep ball kicking in soccer. *Journal of Applied Biomechanics*, *33*(2), 105-111. https://doi.org/10.1123/jab.2016-0040

Weakley, J., Ramirez-Lopez, C., McLaren, S., Dalton-Barron, N., Weaving, D., Jones, B., Till, K., & Banyard, H. (2020). The effects of 10%, 20%, and 30% velocity loss thresholds on kinetic, kinematic, and repetition characteristics during the barbell back squat. *International Journal of Sports Physiology and Performance*, *15*(2), 180-188. https://doi.org/10.1123/IJSPP.2018-1008

Weakley, J., Till, K., Sampson, J., Banyard, H., Leduc, C., Wilson, K., Roe, G., & Jones, B. (2019). The effects of augmented feedback on sprint, jump, and strength adaptations in rugby union players after a 4-week training program. *International Journal of Sports Physiology and Performance*, *14*(9), 1205-1211. https://doi.org/10.1123/ijspp.2018-0523

Wirth, K., Hartmann, H., Sander, A., Mickel, C., Szilvas, E., & Keiner, M. (2016). The impact of back squat and leg-press exercises on maximal strength and speed-strength parameters. *Journal of Strength and Conditioning Research*, *30*(5), 1205-1212. https://doi.org/10.1519/JSC.0000000000001228

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, *38*(3), 285-288. https://doi.org/10.1136/BJSM.2002.002071

Young, W.B., & Rath, D.A. (2011). Enhancing foot velocity in football kicking: The role of strength training. *Journal of Strength and Conditioning Research*, *25*(2), 561-566. https://doi.org/10.1519/JSC.0b013e3181bf42eb

Ziv, G., & Lidor, R. (2011). Physical characteristics, physiological attributes, and on-field performances of soccer goalkeepers. *International Journal of Sports Physiology and Performance*, *6*(4), 509-524. https://doi.org/10.1123/ijspp.6.4.509

Submitted: May 20, 2023
Accepted: November 3, 2024
Published Online First: December 3, 2024

Amador García Ramos, Ph.D.
Department of Physical Education and Sport
Faculty of Sport Sciences
University of Granada La Crosse
Cam. de Alfacar, 21, Norte, 18071 Granada
Phone: +34677815348
E-mail: amagr@ugr.es

IS THERE A DIFFERENCE BETWEEN RHYTHMIC AND ARTISTIC GYMNASTS IN ACTIVE AND PASSIVE FLEXIBILITY OF THE LOWER LIMBS?

Elena Milenković, Josipa Radaš, and Lucija Milčić

University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Original scientific paper
DOI 10.26582/k.56.2.5

Abstract:

Flexibility is the first connection between rhythmic and artistic gymnasts, but it is also motor ability that distinguishes them at the sporting level. The main goal of this research was to determine whether there was a significant difference in active and passive flexibility of the lower limbs among rhythmic and artistic gymnastics competitors. The sample of participants consisted of 18 gymnasts, out of which nine were rhythmic gymnasts and the other nine artistic gymnasts, from the junior and senior age category (13 to 18 years). In the research, the following tests were used to assess active and passive flexibility, constructed by the International Gymnastics Federation (FIG): front split with hand support (FSWH), front split without hand (FSWOH), side split with hand support (SSWH), side split without hand (SSWOH), back split "penche" (BSP), back split with hand support (BSWH), and forward-backward split between two blocks (FBS). In order to analyse the difference between the two groups of participants (rhythmic and artistic gymnasts) in flexibility tests, Mann-Whitney U test was used, the test for independent samples. To determine the difference between the dominant and non-dominant leg, Sign test was used to see whether there was a statistically significant difference between the arithmetic means of the tests performed by the rhythmic and artistic gymnasts, with an error of $p<.05$. Results showed statistically significant difference between the rhythmic and artistic gymnasts in tests of active and passive flexibility. Differences are in the dominant leg, which was expected because each element is performed on the dominant leg.

Key words: *flexibility, dynamic, inactive, preferred leg, non-preferred leg*

Introduction

Both sports, rhythmic and artistic gymnastics belong to the conventional aesthetic disciplines where the movement is prescribed by the Code of Points (FIG, 2022b, 2022a). Women artistic gymnastics consists of four disciplines: vault, uneven bars, balance beam, and floor. In rhythmic gymnastics all routines are performed on the floor using five apparatuses: rope, hoop, ball, clubs, and ribbon. The disciplines of women's artistic gymnastics mostly similar in some leaps, jumps, hoops, and turns to the rhythmic gymnastics are floor and balance beam. One of the most fundamental physical components of rhythmic gymnastics is flexibility. What mostly differs artistic and rhythmic gymnastics from non-aesthetic sports is flexibility or ROM (range of motion) (Sands, et al., 2016a). Ability to reach ROM during the performance of technical aspects greatly influences the level of technical and artistic excellence that rhythmic gymnasts are able to accomplish. A strong correlation between flexibility degree and skill of rhythmic gymnasts has been found in several studies (Boligon, Deprá & Rinaldi, 2015; Vernetta, Peláez-Barrios, & López-Bedoya, 2020). There are three types of flexibility: dynamic, active, and passive (also known as static) flexibility (Alter, 1998; Prentice, 1994). The maximum range of motion a joint can attain with the help of an external force, like gravity or manual assistance, without taking into account movement speed or muscular exertion, is known as passive flexibility (Prentice, 1994). The greatest range of motion an athlete may achieve with momentum and his or her own muscle work is known as dynamic flexibility (Prentice, 1994). The maximum range of motion that an athlete may achieve utilizing only their own muscles is known as active flexibility (Alter, 1998).

There are five widely used stretching techniques: proprioceptive neuromuscular facilitation (PNF), dynamic stretching, ballistic stretching, static-active stretching, and static stretching. The majority of the literature indicates that PNF is the most successful method, however, vibration training has also started to gain popularity as an effective technique for increasing flexibility in recent years (Uzunov, 2008). Middle childhood, the period from six to eleven years, is emphasized as a key time for the development of flexibility and is considered a "window of opportunity" (Lloyd & Oliver, 2012). One of the possible mechanisms behind this assumption is increased flexibility and reduced muscle-tendon stiffness, associated with childhood, which enables a greater range of motion to be achieved and thus can make flexibility training more effective (Kubo, Kanehisa, Kawakami, & Fukanaga, 2001). A meta-analysis by Donti, Konrad, Panidi, Dinas, and Bogdanis (2022), dealing with the issue of whether there is a difference in the effectiveness of flexibility training in children (6-11 years) and adolescents (12-18 years), showed that stretching, without differences, successfully improved range of motion in both children and adolescents, which indicates a contradiction. It is also necessary to emphasize that the importance of flexibility is specific to each sport, so in sports such as gymnastics and dance, children must be able to perform technical elements with a very large range of motion from a young age (7-9 years) (Sands, et al., 2016). Apart from the influence of training, the next question that arises is the influence of puberty on flexibility. During puberty, bones grow faster than muscles, which can result in reduced muscle-tendon extensibility of postural and biarticular muscles, thus limiting ROM (Philippaerts, et al., 2006; Robles-Palazón, et al., 2022; Tanner, 1987). In the research by Mandroukas, Metaxas, Michailidis, and Metaxas (2023), the aim was to investigate and compare the passive ROM in the joints and the strength of rhythmic gymnasts, artistic gymnasts, and controls in the pre-adolescent period. The study concluded that rhythmic gymnasts demonstrated significantly greater flexibility compared to artistic gymnasts, likely influenced by their sport-specific training and demands. Moreover, significant variations in hip flexion between the left and right legs were observed among rhythmic gymnasts (Mandroukas, et al., 2023). These findings underscore the beneficial effects of both rhythmic and artistic gymnastics training on neuromuscular function and relative muscle strength in pre-adolescent individuals (Mandroukas, et al., 2023). The work by Haywood (1980), who investigated the strength and flexibility of rhythmic gymnasts before and after the onset of menstruation, also indicates that there are no significant differences in strength and flexibility before and after the onset of menstruation. The ideal time to develop passive flexibility is between five and eight years of age (Uzunov, 2008). The ideal method for developing passive flexibility according to recommendations (Davis, Ashby, McCale, McQuain, & Wine, 2005; Uzunov, 2008), is holding a stretch for five to 60 seconds with the first 20 to 30 seconds having the highest benefit to duration ratio (Brandy & Iron, 1994; Brandy, Iron, & Biggler, 1997, 1998; McNair, Dombroski, Hewson, & Stanley, 2000; Uzunov, 2008). Recommendations for stretching frequency vary from one to three times per day to five times per week (Davis, et al., 2005). When it comes to preventing injuries, passive flexibility may be especially important for younger gymnasts performing quick, dynamic movements(Funk, Swank, Mikla, Fagan, & Farr, 2003). Studies reveal that, compared to static flexibility, dynamic flexibility, which also includes active flexibility, is far more important for sports performance (McNair, et al., 2000; Prentice, 1994; Roberts & Wilson, 1999; Uzunov, 2008). There are investigations into flexibility and its influence on performance, especially in aesthetic sports. Boligon et al. (2015) have determined how flexibility affects the execution and validation of movements that are typical for rhythmic gymnastics. Silva et al. (2019) investigated genetic predisposition in the definition of the elite rhythmic gymnasts' flexibility phenotype. The tests used to measure flexibility in gymnastics disciplines are reviewed by Vernetta et al. (2020) using data from January 2005 to March 2020 from the PubMed, WOS, Scopus, Sport Discus, and Google Scholar databases. Hölbling, Grafinger, Baca, and Dabnichki (2020) have created a model prototype of a device that increases hip joint ROM, uses flexibility-enhancement reflexes, and offers suitable means for strength training. The purpose of the study by Berisha and Oktay (2021) was to perform a biomechanical analysis of the use of active flexibility in artistic gymnastics movements requiring flexibility, strength, power and other motor skills in addition to mobility (actively moving through a range of motion). Dallas and Kirialanis (2013) investigated how different whole body vibration (WBV) settings affected the flexibility and jumping ability of artistic gymnasts. The goal of the research by Irurtia, Busquets, Carrasco, Ferrer, and Marina (2010) was to describe how flexibility changed in a group of fifteen teenage male gymnasts throughout the period of the entire gymnastics season. D'Anna and Gomez Paloma's (2015) overview of the literature should facilitate the organisation of training plans aiming at improving gymnasts' performance. Acute changes in hip extension flexibility in rhythmic gymnasts were investigated and compared by Karloh et al. (2010) using two different stretching methods. Papia, Bogdanis, Taubekis, Donti, and Donti (2018) researched how an acute session of extended static stretching affected the hip and knee joint range of motion (ROM) and the height of the countermovement jump (CMJ) in nineteen female Gymnastics for All gymnasts. Batista, Garganta, and Avila-Carvalho (2019b) examined potential functional asymmetries in flexibility in gymnasts from Brazilian and Portuguese national teams of rhythmic gymnasts and compared their strength and flexibility levels. In another study the interaction between technical execution score and physical fitness in rhythmic gymnasts of different performance levels was investigated (Donti, Bogdanis, Kritikou, Donti, & Theodorakou, 2016). The purpose of the study by Batista Santos, Bobo Arce, Lebre, and Ávila-Carvalho (2017) was to determine levels of lower limb flexibility and any potential asymmetry indicators between the dominant and non-dominant leg in the gymnasts in Portugal Junior 1st Division. Batista, Garganta, and Avila-Carvalho (2019a) examined both passive and active flexibility and compared them among Portuguese rhythmic gymnasts competing at different levels. Meanwhile, Santos, Lemos, Lebre, and Carvalho (2015) assessed five high-level junior gymnasts (aged 13.60 ± 0.25 years) throughout a sports season for their levels of preferred and non-preferred lower limb active and passive flexibility.

Rhythmic elements of artistic gymnastics are performed on balance beam and floor and some of them are very common elements in rhythmic gymnastics. The main purpose of comparing active and passive flexibility in rhythmic and artistic gymnasts was to observe the difference in flexibility between the dominant and non-dominant leg. Namely, gymnasts (artistic and rhythmic) usually perform elements on the dominant leg and the non-dominant leg is neglected. The aim is to highlight the importance of both active and passive flexibility and to assist coaches in training planning. Our research fills a critical gap by specifically focusing on both active and passive flexibility, providing new insights lacking in the current literature. Insufficient flexibility in artistic gymnastics impedes performance and results in the form of deductions from the final exercise score, particularly in routines requiring five acrobatic and three dance elements on both the floor and balance beam. Non-compliance with dance element rules leads to their non-recognition, directly impacting the final exercise score. For example, failing to execute a leap jump with leg separations at 180° results in deductions ranging from 0.10 to 0.30 points. Leg separations under 135° may result in the element being categorized differently according to the Code of Points, or receiving no difficulty value (FIG, 2022b). Connections of elements, especially on balance beam, connection of turns, must be performed with a step in to turn on the opposite leg (FIG, 2022b). In exercises on beam and floor, the artistry of execution is lost and dance elements are performed at a rather poor level, and more attention is paid to the weight values of acrobatic elements. In this way, the dance elements serve as a „break“ from the acrobatics in the exercise and they are not performed at the level at which they should be performed. Therefore, exercises lose their artistry and become robotic. Same as with artistic gymnasts, rhythmic gymnasts also perform most of the elements only on the dominant leg. In rhythmic gymnastics importance of passive and active flexibility and large ROM is even more emphasised than in artistic gymnastics. Deductions for insufficient flexibility in elements such as balances, rotations, leaps, acrobatic elements, etc., go from 0.1 points for small deviations of body segments, 0.3 points for medium deviations of body segments, to 0.5 points for large deviations of body segments (FIG, 2022a). If the rhythmic gymnast has a large deviation of the body segments during the performance of the element, in addition to the execution penalty of 0.5 points, the commission of BD judges does not count the value of the performed element, whereby the gymnast loses points again (FIG, 2022a). In addition to the execution commission, the artistry commission can also deduct points for insufficient ROM during performance of elements. If the movements of the body segments are not performed with maximum amplitude, width and extension, the artistry commission gives a penalty of 0.3 to 0.5 points (FIG, 2022a).

The importance of flexibility and great ROM in rhythmic gymnastics can be seen in many body difficulties (jumps/leaps, balance, and rotations), as well as in pre-acrobatic elements. For example, in jumps like stag or split leap (with or without ring/back bend of the trunk) and its variations (switch leap, or turning leap “jete en tournant”), balances like front, side or back split (with or without help, with the trunk backward/forward at horizontal/below horizontal, etc.), rotations in front/side/back split with or without help, also with the trunk backward/forward at or below horizontal (“penche”, “Kabaeva”, etc,) and pre-acrobatic elements such as walkovers forwards and backwards, cartwheels, chest rolls etc. For every difficulty of the body and pre-acrobatic element that is not executed with satisfactory amplitude, execution judges deduct 0.1-0.5 pointsfor execution from, depending on how big the deviation of the body segments is.

Goals and hypotheses

The main goal of this research paper is to determine whether there is a significant difference in active and passive flexibility of the lower limbs among rhythmic and artistic gymnastics competitors. Through the conducted tests, coaches gain an insight into the difference between the dominant and non-dominant limb and in this way, they can plan the further training process, so that the differences in limb flexibility, if any, can be reduced and the performance on both limbs can be improved. Therefore, the following hypotheses were set:

H_0: There is no difference in active and passive flexibility between rhythmic and artistic gymnastics competitors.

H_1: There is a statistically significant difference in active and passive flexibility between rhythmic and artistic gymnastics competitors.

Methods

Participants

The sample of participants consisted of 18 gymnasts of which nine were rhythmic gymnasts and nine artistic gymnasts from junior and senior age category (13 to 18 years). According to the Participant Classification Framework, gymnasts belonged to the elite/international level (McKay, et al., 2022). Mean values of body height (cm) (Table 1) for rhythmic gymnasts was 160 cm, body mass 47.89 kg, and BMI 18.28. Artistic gymnasts had mean height values of 158 cm, body mass: 50.89 kg, and BMI= 20.32. BMI was calculated by the following formula: $BMI = \frac{weight\ (kg)}{height\ (m^2)}$

Table 1. Descriptive parameters of basic anthropometric charatcteristic – artistic and rhythmic gymnats

Variable	Valid N AG	Valid N RG	Min AG	Mean RG	Mean AG	Min RG	Max AG	Max RG	Std Dev AG	Std Dev RG
Height (m)	9	9	1,58	1,60	1,53	1,38	1,64	1,79	0,04	0,14
Weight (kg)	9	9	50,89	47,89	47,00	32,00	56,00	60,00	2,98	10,84
BMI (kg/m^2)	9	9	20,32	18,28	19,70	16,00	20,90	20,00	0,44	1,63

Note. AG - artistic gymnasts; RG - rhythmic gymnasts

Both groups of gymnasts trained in SC Lučko and were of the highest competition level (A programme). They had their training sessions six days a week, from Monday to Saturday, for 6-8 hours a day. The precondition for participation in the research was the absence of any injuries and any other conditions that could negatively affect the performance of the tests or be risky for further deterioration of the gymnast’s health. Before the actual start of the research, the trainees and coaches were informed about the goals and potential risks and an informed consent for voluntary participation in the research was signed (approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb). For trainees who were minors, informed consents were signed by their parents.

Description of protocols, measuring instruments and variables

The research was conducted in the sports hall SC Lučko, where the gymnasts have their training routine. Before the tests, the gymnasts warmed up for at least an hour, so that the tests could be performed with the maximum possible amplitude. All respondents did a gymnastic specific warm-up session for at least an hour. The warm-up session consisted of passive and active stretching exercises combined with strength (1-min step out on both extremities, 5-min front, side and back splits on both extremities, 20 x back bends) plus 20 minutes of ballet exercises (20 x *releve*, 10 x b*attement tendu*, 10 x *battement jete*, 10 x *grand battement* jete). After warming up, gymnasts approached the measurer individually and, after explanation and demonstration, performed all seven tests on both extremities. After the first gymnast completed the tests, the next was called and so on until the last gymnast. Each test was recorded and photographed with the camera of a Samsung Galaxy S21+ mobile phone, 30 fps (frame per second) three times whereby the final position on each performed test had to be held for at least two seconds. The camera was 3-m away from the participants, so that the entire performance of the test could be recorded without interruption. No special programme was used for image analysis. The pictures were put into Microsoft Word and lines were drawn according to the degrees that determined the criteria. When the measurer was taking pictures and recording the performance of the test, no tripod was used, the cell phone was held by the hand.

The measurer used a cell phone to record and take pictures of the entire procedure in order to analyse and assign a mark based on a specific criterion afterwards by three Croatian gymnastics experts (three Brevet judges), who judge major gymnastics competitions (World Cups, European and World Championships) and participate in annual educations conducted by the FIG (World Gymnastics Federation). For each test, criteria were determined by degrees (from 0° to 90°+) for which a corresponding grade (1-10) was given. Grade 1 means that the test performance was the poorest, while grade 10 means that the test performance was the best (Figure 1). In the research, the following tests, constructed by the International Gymnastics Federation (FIG) (Dias, Aleksandrova, Lebre, Bobo, & Fink, 2021) were used to assess active and passive flexibility: front split with hand support (FSWH), front split without hand support (FSWOH), side split with hand support (SSWH), side split without hand support (SSWOH), back split „penche“ (BSP), back split with hand support (BSWH), and forward-backward split between two blocks (FBS). The tests: front split with hand support, side split with hand support, back split with hand support, and forward-backward split between two blocks were used to assess passive flexibility, while the front split without hand support, side split without hand support, and back split "penche" were used to assess active flexibility. All tests were performed on both lower limbs (dominant/non-dominant), with the test always starting with the non-dominant leg first. None of the tested gymnasts fell during the performances of the tests in this research. In the case of a fall during the performance, gymnasts can repeat it for a second time, but if the gymnasts are unable to perform the test, the score for their performance was rated as 0. In our research, a similar angular evaluation was employed to align with the criteria published by the International Gymnastics Federation (FIG). This ensured that our methodology was consistent with the established standards, thus enhancing the reliability and comparability of the results.

Table 2 shows the description of the variables and criteria used. For each test (Table 3), criteria were determined, according to which the gymnast was awarded a mark from one to 10. Mark 1 indicated the poorest performance, while mark 10 indicated the best performance.

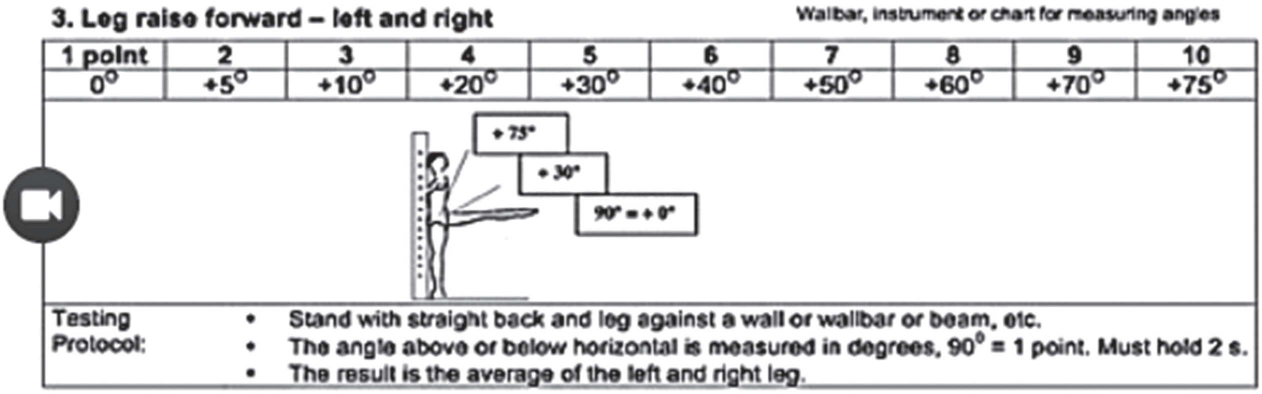


Figure 1. Testing procedure for leg raise forward – left and right.

Table 2. Description of variables

Variable	Description of the variable	Mark
FSWH DOM	Front split with hand support – dominant leg	1 – 10
FSWH NDOM	Front split with hand support – non-dominant leg	1 – 10
FSWOH DOM	Front split without hand support – dominant leg	1 – 10
FSWOH NDOM	Front split without hand support – non-dominant leg	1 – 10
SSWH DOM	Side split with hand support – dominant leg	1 – 10
SSWH NDOM	Side split with hand support – non-dominant leg	1 – 10
SSWOH DOM	Side split without hand support – dominant leg	1 – 10
SSWOH NDOM	Side split without hand support – non-dominant leg	1 – 10
BSP DOM	Back split "penche" – dominant leg	1 – 10
BSP NDOM	Back split "penche" – non-dominant leg	1 – 10
BSWH DOM	Back split with hand support – dominant leg	1 – 10
BSWH NDOM	Back split with hand support – non-dominant leg	1 – 10
FBS DOM	Forward-backward split between two blocks – dominant leg	1 – 10
FBS NDOM	Forward-backward split between two blocks – non-dominant leg	1 – 10
TBF	Trunk bend forwards	1 – 10
SMT	Shoulder mobility test	1 – 10

Table 3. Criteria and marks for each range of degrees

1	2	3	4	5	6	7	8	9	10
0-10°	10 - 20°	20 - 30°	30 - 40°	40 - 50°	50 - 60°	60 - 70°	70 - 80°	80 - 90°	90°+

Front split with hand support (FSWH)

The gymnast stands on her full feet, with the body upright and side facing the Swedish ladder, while holding on to the crossbar at waist level with the nearer hand (Figure 2). At the signal of the measurer, the gymnast raises the non-dominant leg fully extended in front of the body and grabs it with the same hand, pulling it towards the chest as close as possible. When the maximum amplitude has been reached, the gymnast has to keep the front leg position for a minimum of two seconds. During this time, the measurer records and takes pictures of the performance with a cell phone and the recording is later used for analysis and scoring according to certain criteria. It is important to emphasize that all segments of the body of the gymnast must be in a harmonious position: both the shoulders and hips are facing forward, the knees and feet of both legs are fully extended, and the back is straight. When the gymnast has performed the test on the non-dominant leg, the same test is repeated on the dominant leg, only now facing the ladder with her other side.

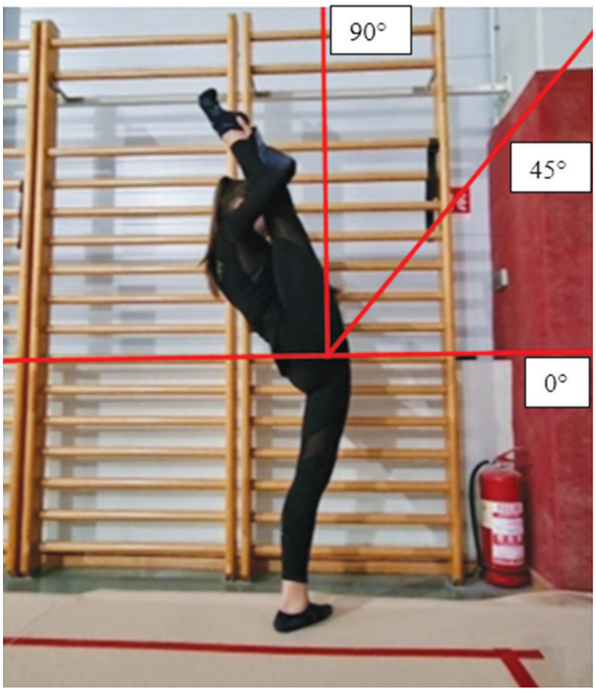


Figure 2. Front split with hand support—Test 1.

Front split without hand support (FSWOH)

The gymnast stands on the full feet, with the body upright, and side facing the Swedish ladder, while holding on to the crossbar at waist level with the nearer hand (Figure 3). At the measurer's signal, the gymnast raises the non-dominant leg in front of the body as high as possible and holds the achieved position for at least two seconds without the help of the hand. The same-sided arm is raised and extended above the head. The entire process is recorded and photographed with a mobile phone by the measurer, so that later analysis can be done, and a mark can be assigned according to a certain criterion. All segments of the body of the gymnast must be in a harmonious position: the shoulders and hips are facing forward, the knees and foot of the raised leg maximally extended, and the back is straight. After performing the test on the non-dominant leg, the gymnast repeats the task on the dominant leg and turns the other side to the ladder.

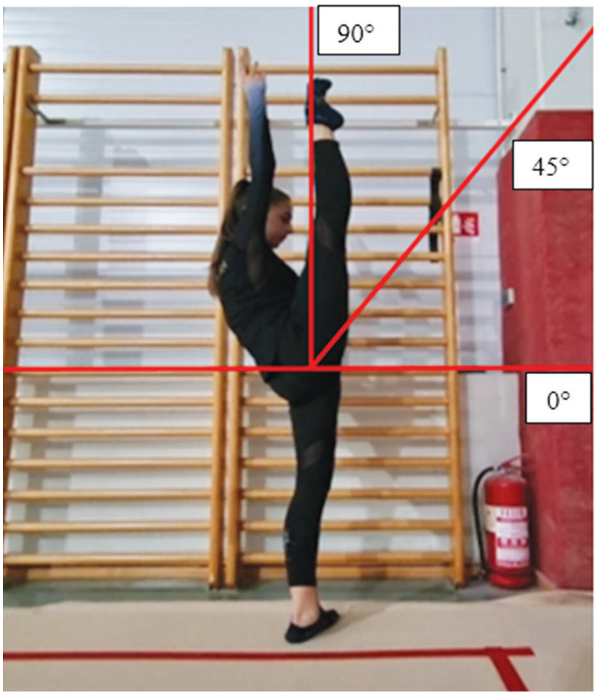


Figure 3. Front split without hand support—Test 2.

Side split with hand support (SSWH)

The gymnast stands on full feet, with the back turned to the Swedish ladder, holding on to the crossbar with one hand at waist level (Figure 4). At the signal of the measurer, the gymnast raises laterally the non-dominant leg and grabs it with the same hand, pulling it towards the shoulder as much as possible. The achieved split position must be maintained for a minimum of two seconds, during which the measurer records and takes pictures of the entire process of performing the task. During the performance, the body of the gymnast should be in a harmonious position, with the knees and foot of the raised leg maximally extended, while the body is upright and looking straight ahead. The same task is executed with the dominant leg.

Side split without hand support (SSWOH)

The gymnast stands on full feet, with the back turned to the Swedish ladder, holding on to the crossbar with one hand at waist height and the other laterally raised shoulder height (Figure 5). At the signal of the measurer, the gymnast raises the non-

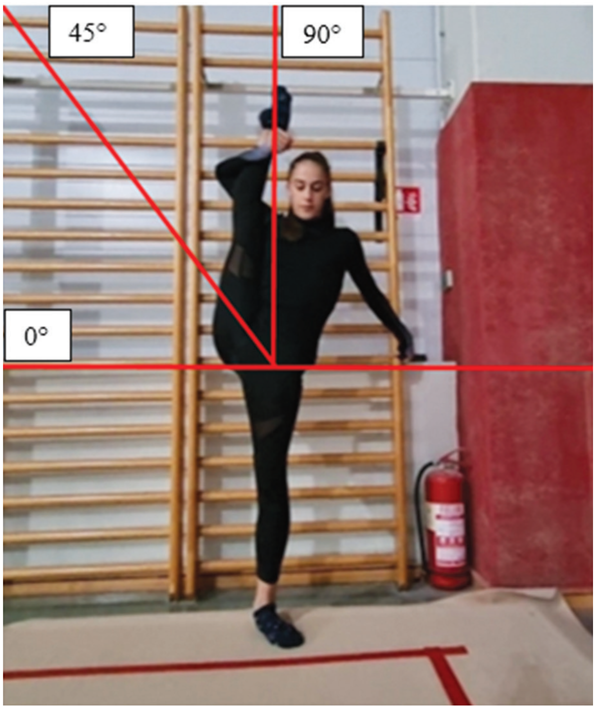


Figure 4. Side split with hand support—Test 3.

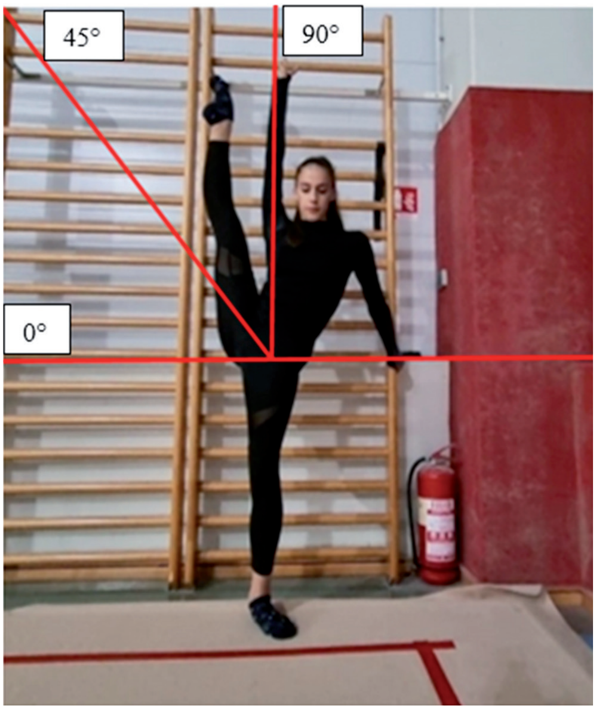


Figure 5. Side split without hand support—Test 4.

dominant leg on the side of the body as high as possible and maintains the achieved position for a minimum of two seconds, without the help of the hand. The task is recorded and photographed by the measurer with a mobile phone, from start to finish. The body of the gymnast during the test performance must be upright, without leaning to the side and with the knees and foot of the raised leg maximally extended. The task is then executed with the dominant leg.

Back split "penche" (BSP)

The gymnast stands with her trunk bent forward below horizontal, with both the legs and arms extended (Figure 6). At the measurer's signal, the gymnast does a back split into a "penche" position with the non-dominant leg as high as possible and holds the position for a minimum of two seconds. It is important to emphasize that the weight of the gymnast's body should not be on the hands but on the standing leg. The body of the gymnast also must be in a harmonious position, with both shoulders in the same plane, with both knees and the foot of the upper leg stretched to the maximum. The same task is executed with the dominant leg, while the measurer is recording and taking pictures of the entire process with a mobile phone.

Back split with hand support (BSWH)

The gymnast stands with her chest facing the Swedish ladder, holding on to the crossbar at waist height with both hands (Figure 7). At the signal of the measurer, the gymnast performs a back split with the non-dominant leg as high as possible and

Figure 6. Back split "penche"—Test 5.

grabs the leg with the opposite hand, trying to perform the position of the full, extended split. It is allowed to slightly bend the trunk forwards during the performance of the task, provided that both shoulders are in the same plane and look forwards. Both legs and the foot of the upper leg must be maximally extended. The task is then executed with the dominant leg, while the measurer records the performance and takes pictures with a mobile phone.

Forward-backward split between two blocks (FBS)

To perform this test, two gymnastic blocks, chairs or any kind of elevation are needed. The blocks for both legs must be of the same height (Figure 8). The gymnast performs a forward-backward split between two blocks, while trying to achieve the maximum amplitude of the split and touch the ground with the thigh of the front leg. The hands can be placed on the front block or extended up, provided that the body is upright or slightly bent forward. The body that rests completely on the front leg or deviates from the harmonious position in any way is considered an incorrect performance of the task and is not valid. Both legs and both feet must also be maximally extended. The gymnast must maintain the achieved position of the split for a minimum of two seconds, while the measurer takes pictures of the final position with the mobile phone. The test is repeated on the other leg/side.

Figure 7. Back split with hand support—Test 6.

Data processing

For simple data analysis and processing, Microsoft Excel 365 was used for input and better transparency, while Statistica 14.0.0.15 was used for statistical analysis. Mean, minimum, maximum, standard deviation and normality of distribution were used as descriptive indicators for both groups of participants. The effect size parameter was used to show the practical significance of the results. Effect size was tested by Cohen's d index (Cohen, 1988) with Hedges correction for small samples. In order to analyse the difference between the two groups of participants (rhythmic and artistic gymnasts) in tests of flexibility Mann-Whitney U test was used, the test for independent samples. To determine the difference between the dominant and non-dominant leg Sign test was used that shows whether there is a statistically significant difference between the arithmetic means of the tests performed by rhythmic and artistic gymnasts, with an error of $p<.05$.

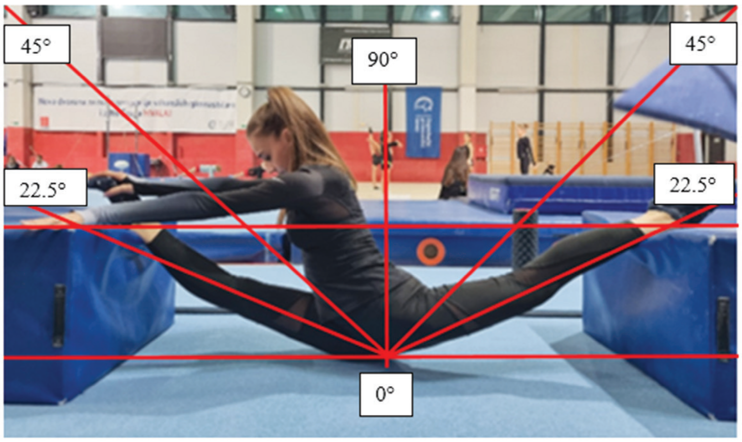


Figure 8. Forward-backward split between two blocks—Test 7.

Results

In Tables 4 and 5 descriptive results of artistic and rhythmic gymnasts are presented for all the flexibility tests.

According to the results presented in Table 6, a statistically significant difference is visible in the active and passive flexibility of the lower limbs between the rhythmic and artistic gymnastics competitors, with an error of $p<.05$. Therefore, the null (H_0) hypothesis can be rejected and the alternative (H_1) hypothesis accepted. Statistically significant difference is obvious in the following tests: FSWH DOM, FSWOH DOM, SSWH DOM, SSWH NDOM, SSWOH DOM, BSP DOM, BSWH DOM, BEWH NDOM, and FBS DOM. Greater differences between the two groups of gymnasts were obtained

Table 4. Descriptive indicators – artistic gymnastics

Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
FSWH DOM	9	8.11	6	10	1.05
FSWH NDOM	9	7.33	6	9	1.22
FSWOH DOM	9	5.44	4	7	0.88
FSWOH NDOM	9	3.89	2	6	1.27
SSWH DOM	9	8.22	7	9	0.67
SSWH NDOM	9	6.89	5	9	1.17
SSWOH DOM	9	5.67	5	7	0.87
SSWOH NDOM	9	4.11	3	6	1.17
BSP DOM	9	8.33	7	10	1.00
BSP NDOM	9	7.78	6	10	1.20
BSWH DOM	9	4.11	3	6	1.17
BSWH NDOM	9	3.00	2	4	0.71
FBS DOM	9	4.33	1	7	2.12
FBS NDOM	9	2.67	1	6	1.94
TBF	9	10.00	10	10	0.00
SMT	9	9.78	8	10	0.67

Table 5. Descriptive indicators – rhythmic gymnastics

Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
FSWH DOM	9	9.33	8	10	0.71
FSWH NDOM	9	8.22	7	9	0.67
FSWOH DOM	9	7.33	5	9	1.58
FSWOH NDOM	9	4.78	2	7	1.39
SSWH DOM	9	9.78	9	10	0.44
SSWH NDOM	9	8.33	7	9	0.71
SSWOH DOM	9	7.56	6	9	1.13
SSWOH NDOM	9	4.89	4	5	0.33
BSP DOM	9	9.78	9	10	0.44
BSP NDOM	9	8.56	7	10	0.88
BSWH DOM	9	8.33	5	10	1.80
BSWH NDOM	9	6.11	4	10	1.90
FBS DOM	9	8.33	4	10	2.35
FBS NDOM	9	3.67	1	7	2.12
TBF	9	10.00	10	10	0.00
SMT	9	10.00	10	10	0.00

in passive flexibility tests than in active flexibility tests. We can also see that rhythmic gymnasts are more flexible than artistic gymnasts.

Results of Sign test in Table 7 show that there is statistically significant difference between the dominant and non-dominant legs of artistic gymnasts in four tests.

In Table 8 the differences between the dominant and non-dominant legs of rhythmic gymnasts are presented as obtained in seven tests of flexibility, i.e., in four tests of passive and in three tests of active flexibility.

Discussion and conclusion

The purpose of this study was to examine and compare the flexibility and strength characteristics of rhythmic and artistic gymnasts. The tests of passive flexibility showed greater differences compared to the tests of active flexibility, demonstrating that rhythmic gymnasts have greater flexibility than artistic gymnasts. This was expected, as rhythmic gymnastics places much less importance on explosive strength compared to artistic gymnastics, reflecting different physical demands and training approaches. The effect sizes calculated

Table 6. Results of Mann-Whitney U test for independent samples

Variable	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N group 1	Valid N group 2	2*1sided exact p	Cohen's d
FSWH DOM	113.00	58.00	13.00	2.38	0.02	2.51	0.01	9	9	0.01*	1.24 (large)
FSWH NDOM	103.00	68.00	23.00	1.50	0.13	1.57	0.12	9	9	0.14	0.85 (medium)
FSWOH DOM	112.50	58.50	13.50	2.34	0.02	2.41	0.02	9	9	0.01*	1.38 (large)
FSWOH NDOM	101.00	70.00	25.00	1.32	0.19	1.36	0.17	9	9	0.19	0.66 (medium)
SSWH DOM	123.00	48.00	3.00	3.27	0.00	3.44	0.00	9	9	0.00*	2.64 (large)
SSWH NDOM	114.00	57.00	12.00	2.47	0.01	2.55	0.01	9	9	0.01*	1.46 (large)
SSWOH DOM	118.00	53.00	8.00	2.83	0.00	2.89	0.00	9	9	0.00*	1.77 (large)
SSWOH NDOM	101.50	69.50	24.50	1.37	0.17	1.57	0.12	9	9	0.16	0.78 (medium)
BSP DOM	117.50	53.50	8.50	2.78	0.01	2.95	0.00	9	9	0.00*	1.65 (large)
BSP NDOM	102.50	68.50	23.50	1.46	0.15	1.51	0.13	9	9	0.14	0.7(medium)
BSWH DOM	124.00	47.00	2.00	3.36	0.00	3.40	0.00	9	9	0.00*	2.53 (large)
BSWH NDOM	124.00	47.00	2.00	3.36	0.00	3.42	0.00	9	9	0.00*	1.73 (large)
FBS DOM	116.50	54.50	9.50	2.69	0.01	2.73	0.01	9	9	0.00*	1.63 (large)
FBS NDOM	98.50	72.50	27.50	1.10	0.27	1.12	0.26	9	9	0.26	0.45 (small)
TBF	85.50	85.50	40.50	-0.04	0.96			9	9		0.00 (small)
SMT	90.00	81.00	36.00	0.35	0.72	0.89	0.37	9	9	0.73	0.63 (medium)

Note. *Significant difference, p<.05; Cohen's d – effect size.

Table 7. Sign test artistic gymnasts' difference between the dominant and non-dominant leg

Pair of variables	No. of non-ties	Percent v < V	Z	p-value
FSWOH DOM & FSWOH NDOM	8	0.00	2.47	0.01*
SSWH DOM & SSWH NDOM	8	0.00	2.47	0.01*
SSWOH DOM & SSWOH NDOM	8	0.00	2.47	0.01*
FBS DOM & FBS NDOM	8	0.00	2.47	0.01*

Note. *Significant difference, p<.05.

Table 8. Sign test rhythmic gymnasts' difference between the dominant and non-dominant leg

Pair of variables	No. of non-ties	Percent v < V	Z	p-value
FSWH DOM & FSWH NDOM	7	0.00	2.27	0.02*
FSWOH DOM & FSWOH NDOM	8	0.00	2.47	0.01*
SSWH DOM & SSWH NDOM	9	0.00	2.67	0.01*
SSWOH DOM & SSWOH NDOM	9	0.00	2.67	0.01*
BSP DOM & BSP NDOM	8	0.00	2.47	0.01*
BSWH DOM & BSWH NDOM	8	0.00	2.47	0.01*
FBS DOM & FBS NDOM	9	0.00	2.67	0.01*

Note. *Significant difference, p<.05.

provide insight into the practical significance of the differences observed between the groups. Here, we discuss the implications of these effect sizes: small, medium and large effect size (from small to large differences between the groups). Overall, the magnitude of these effects underscores the varying degrees of practical significance in the differences between the groups. Large effect sizes highlight substantial differences that are likely to be of high practical importance, while medium effect sizes indicate meaningful differences, and small effect sizes suggest minor differences. These insights can guide future research and decision-making processes. Differences refer predominantly to the dominant leg, which was expected because each gymnastic element is performed on the dominant leg. For example, in rhythmic gymnastics, there are jumps/leaps like stag leap with a ring or back bend of the trunk, split leap with a ring or back bend of the trunk, turning stag leap (with a ring or back bend of the trunk), turning split leap "jete en tournant" (with ring or back bend of the trunk), switch stag or split leap, etc. Jumps that are usually performed in artistic gymnastics on floor and beam are Johnson jump (90°, 180°), split leap, switch leap, switch leap to ring position, straddle pike jump, split jump with turns (180°, 360°, 540°), ring jump, and illusion turn (360°). In both artistic and rhythmic gymnasts there are differences between their dominant and non-dominant legs. According to the results, the gymnasts' levels of active and passive flexibility were higher for their preferred lower limb than for their non-preferred lower limb (Santos, et al., 2015). These results are similar to results in some investigations. The main findings showed that 86.7% of the Portuguese junior gymnasts had high flexibility asymmetry ratings of different magnitudes between their dominant and non-dominant limbs (Batista Santos, et al., 2017). Variations in passive and active flexibility between the non-preferred and preferred lower limbs were seen in all groups, degree of asymmetry decreases as the level of competition increases (Batista, et al., 2019a). The most likely explanation could be that elements are usually performed on the dominant leg. Different impact of stretching on the range of motion was however shown when the volume of the stretching load was asked (Donti, et al., 2022). Stretching should be trained both for active and passive flexibility, also at the beginning of a training session in the dynamic mode and at the end of session in the static mode. According to a number of examined studies, the research conducts some reflections on the different stretching strategies used during the gymnastics training phases (warming up, cooling down), which are helpful in organizing training sessions that result in the best performance (D'Anna & Paloma, 2015). Long static stretching improves range of motion (ROM) but has no detrimental effects on CMJ performance in very young female gymnasts who have undergone flexibility training (Papia, et al., 2018). After six weeks, the static stretch and Mulligan's Long Leg Traction Group 1 (Mulligan concept) showed statistically significant gains in acute changes compared to Group 2 (static stretching) (Karloh, et al., 2010). Also, flexibility is not the same across different ages. While adolescents reacted equally to both higher and lower volumes of stretching load, children showed better results with higher volume of load compared to lower volume of stretching load (Donti, et al., 2022). Depending on the anatomical region tested (lower limbs, upper limbs, or multijoint testing) and the type of flexibility produced (passive or active), flexibility improves across the gymnastics season at various levels of adaptation (Irurtia, et al., 2010). Our study did not seek differences in shoulder flexibility between artistic and rhythmic gymnasts. Shoulder and hip flexibility are the quality that separates elite gymnasts apart from the competition (Donti, et al., 2016). However, this referred to artistic gymnasts. The technical execution score appears to be more influenced by physical fitness at the lower performance level (non-qualifiers) (Donti, et al., 2016). An athlete may not always have good mobility just because they are flexible so understanding the distinctions between mobility and active flexibility is essential for defining functional flexibility (Berisha & Oktay, 2021). Among the many tests conducted, the split, shoulder flexibility, bridge and sit-and-reach tests were the most frequently used ones (Vernetta, et al., 2020). In artistic gymnasts, flexibility and jumping performance improved under both the whole body vibration and static stretching settings, each of which had a unique impact on the variables under investigation (Dallas & Kirialanis, 2013). Although the results obtained show that rhythmic gymnasts were more flexible, i.e., had a greater range of motion than both groups, the question arises whether such a result was a consequence of a different level of maturity (according to Tanner's stage) and delayed puberty and thus bone development (Mandroukas, et al., 2023). This confirms that this stage of maturation has very little influence on the aforementioned abilities in girls who maintained a constant practice of rhythmic gymnastics during the testing period (Haywood, 1980). The small sample size of elite gymnasts meant that we were not able to divide them into distinct age groups. Consequently, this limitation restricts our ability to analyse how developmental stages or maturity levels may have influenced the observed flexibility and strength characteristics. Tringali's research findings indicated a correlation between the COL5A1 CT genotype and both high joint mobility and *genu recurvatum* incidence (Silva, et al., 2019). The research paper showed that there was difference in active and passive flexibility of lower limbs between rhythmic and artistic gymnasts, in favour of rhythmic gymnasts, as well as differences between the dominant and non-dominant lower limb of each gymnast. The differences between the dominant and non-dominant lower limb were smaller in artistic than in rhythmic gymnasts, which did not come as a huge surprise, because flexibility requirements are much higher in rhythmic gymnastics and consequently the way of training that is often mainly focused on working with dominant limb. The coaches can use these results as good guidance for further planning of training and to detect which aspect of flexibility their gymnasts must work on to prevent further development of body asymmetries. Furthermore, there is also a need for further research on body asymmetry occurrences and their influence on performance and incidence of injuries.

Limitation of the study

The authors are aware of the limitations associated with the sample used in this study. Specifically, the small sample size of elite gymnasts limits the ability to generalize the findings beyond top athletes. To address this limitation, future research should include a larger and more diverse sample of gymnasts to allow for findings to be generalized to a broader population, including international competitors, and not just elite athletes.

Furthermore, it would be valuable to conduct international research involving multiple countries. Such studies would provide opportunities for comparing data across different regions and offer a more comprehensive and global perspective on the flexibility and strength characteristics of gymnasts. This approach would help to enhance the understanding of these characteristics across various levels of competition and cultural contexts.

Additionally, future research should explore the evaluation of flexibility measurements through advanced biomechanical analyses using modern technologies. For instance, incorporating motion capture systems, force plates, and other sophisticated measurement tools could provide more detailed and objective data on flexibility and its biomechanical underpinnings. These technologies could help in understanding the mechanisms behind flexibility and in developing more precise and effective training methods for gymnasts.

References

Alter, M.J. (1998). *Sport stretch* (2nd ed.). Champaign, IL: Human Kinetics.

Batista, A., Garganta, R., & Ávila-Carvalho, L. (2019a). Flexibility and functional asymmetry in rhythmic gymnastics. *The Athens Journal of Sports*, *6*(2), 77-94. https://doi.org/10.30958/ajspo.6-2-2.

Batista, A., Garganta, R., & Ávila-Carvalho, L. (2019b). Flexibility and strength in Brazilian and Portuguese gymnasts. *European Journal of Human Movement*, *42*, 138-154.

Batista Santos, A., Bobo Arce, M., Lebre, E., & Ávila-Carvalho, L. (2017). Flexibilidad en gimnasia rítmica: asimetría funcional en gimnastas júnior portuguesas. [Flexibility in rhythmic gymnastics: Functional asymmetry in Portuguese junior gymnasts.] *Apunts Educación Física y Deportes*, *128*, 19-26. https://doi.org/10.5672/apunts.2014-0983.es.(2015/2).120.03

Berisha, M., & Oktay, G. (2021). A biomechanical examination of the differences between active flexibility and mobility in artistic gymnastics. Differences between active flexibility and mobility. *Viref Revista de Educación Física=Pedagogy of Physical Culture and Sports*, *10*(5), 267-274. doi: 10.15561/26649837.2021.0501

Boligon, L., Deprá, P.P., & Rinaldi, I.P.B. (2015). Influence of flexibility in the execution of movements in rhythmic gymnastics [Influência da flexibilidade na execução de movimentos da ginástica rítmica]. *Acta Scientiarum. Health Sciences*, *37*(2), 141-145. doi: 10.4025/actascihealthsci.v37i2.21615

Brandy, W.D., & Irion, J.M. (1994). The effects of time on static stretch on the flexibility of the hamstrings muscles. *Physical Therapist*, *74*(9), 845-850.

Brandy, W.D., Irion, J.M., & Briggler, M. (1997). The effect of time and frequency of static stretching on flexibility of the hamstring muscles. *Physical Therapy*, *77*(10), 1090-1096.

Brandy, W.D., Irion, J.M., & Briggler, M. (1998). The effect of static stretch and dynamic range of motion training on the flexibility of the hamstring muscles. *Journal of Orthopedic and Sports Physical Therapy*, *27*(4), 295-300.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Dallas, G., & Kirialanis, P. (2013). The effect of two different conditions of whole-body vibration on flexibility and jumping performance on artistic gymnasts. *Science of Gymnastics Journal*, *5*(2), 67-77.

D'Anna, C., & Gomez Paloma, F. (2015). Dynamic stretching versus static stretching in gymnastic performance. *Journal of Human Sport and Exercise*, *10*(Special issue 1), S437-S446. https://doi.org/10.14198/jhse.2015.10.Proc1.37

Davis, D.S., Ashby, P.E., McCale, K.L., McQuain, J.A., & Wine, J.M. (2005). The effectiveness of 3stretching techniques on hamstring flexibility using consistent stretching parameters. *Journal of Strength and Conditioning Research*, *19*(1), 27-32.

Dias, H., Aleksandrova, N., Lebre, E., Bobo, M., & Fink, H. (2021). *Age group development and competition program for rhythmic gymnastics*. Lausanne: Fédération Internationale de Gymnastique.

Donti, O., Bogdanis, G.C., Kritikou, M., Donti, A., & Theodorakou, K. (2016). The relative contribution of physical fitness to the technical execution score in youth rhythmic gymnastics. *Journal of Human Kinetics*, *51*(1), 143-152. https://doi.org/10.1515/hukin-2015-0183

Donti, O., Konrad, A., Panidi, I., Dinas, P.C., & Bogdanis, G.C. (2022). Is there a "window of opportunity" for flexibility development in youth? A systematic review with meta-analysis. *Sports Medicine—Open*, *8*(1), 88. https://doi.org/10.1186/s40798-022-00476-1

FIG—Fédération Internationale de Gymnastique. (2022a). *Rhythmic Gymnastics, Code of Points, 2022-2024*. Lausanne: Fédération Internationale de Gymnastique.

FIG—Fédération Internationale de Gymnastique. (2022b). *Women's Artistic Gymnastics, Code of Points, 2022-2024*. Lausanne: Fédération Internationale de Gymnastique.

Funk, D.C., Swank, A.M., Mikla, B.M., Fagan, T.A., & Farr, B.K. (2003). Impact of prior exercise on hamstring flexibility: A comparison of proprioceptive neuromuscular facilitation and static stretching. *Journal of Strength and Conditioning Research*, *17*(3), 489-492.

Haywood, K.M. (1980). Strength and flexibility in gymnasts before and after menarche. *British Journal of Sports Medicine*, *14*(4), 189-192. https://doi.org/10.1136/bjsm.14.4.189

Hölbling, D., Grafinger, M., Baca, A., & Dabnichki, P. (2020). The flexibility trainer: Feasibility analysis, prototype- and test station development for a sports device for hip-joint flexibility and strength enhancement. In *Proceedings of the 8th International Conference on Sport Sciences Research and Technology Support* (icSPORTS 2020) (pp. 22-29). https://doi.org/10.5220/0010019400220029

Irurtia, A., Busquets, A., Carrasco, M., Ferrer, B., & Marina, M. (2010). Flexibility testing in young competing gymnasts using a trigonometric method: One-year follow-up. *Apunts Medicina de l'Esport*, *45*(168), 235-242. https://doi.org/10.1016/j.apunts.2010.05.003

Karloh, M., Santos, R.P., Kraeski, M.H., Matias, T.S., Kraeski, D., & Menezes, F.S. (2010). Static stretch versus Mulligan concept: Flexibility training in gymnasts. *Fisioterapia em Movimento*, *23*(4), 523-533. https://doi.org/10.1590/S0103-51502010000400003

Kubo, K., Kanehisa, H., Kawakami, Y., & Fukanaga, T. (2001). Growth changes in the elastic properties of human tendon structures. *International Journal of Sports Medicine*, *22*(2), 138-143. https://doi.org/10.1055/s-2001-11337

Lloyd, R.S., & Oliver, J.L. (2012). The youth physical development model. *Strength and Conditioning Journal*, *34*(3), 61-72. https://doi.org/10.1519/SSC.0b013e31825760ea

Mandroukas, A., Metaxas, I., Michailidis, Y., & Metaxas, T. (2023). Muscle strength and joint range of motion of the spine and lower extremities in female prepubertal elite rhythmic and artistic gymnasts. *Journal of Functional Morphology and Kinesiology*, *8*(4), 153. https://doi.org/10.3390/jfmk8040153

McKay, A.K.A., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L., Sheppard, J., & Burke, L.M. (2022). Defining training and performance caliber: A participant classification framework. *International Journal of Sports Physiology and Performance*, *17*(2), 317-331. https://doi.org/10.1123/ijspp.2021-0451

McNair, P.J., Dombroski, E.W., Hewson, D.J., & Stanley, S.N. (2000). Stretching at the ankle joint: Viscoelastic responses to hold and continuous passive motion. *Medicine and Science in Sports and Exercise*, *33*(3), 354-358.

Papia, K., Bogdanis, G.C., Taubekis, A., Donti, A., & Donti, O. (2018). Acute effects of prolonged static stretching on jumping performance and range of motion in young female gymnasts. *Science of Gymnastics Journal*, *10*(2), 217-226.

Philippaerts, R.M., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., Bourgois, J., Vrijens, J., Beunen, G., & Malina, R.M. (2006). The relationship between peak height velocity and physical performance in youth soccer players. *Journal of Sports Sciences*, *24*(3), 221-230. https://doi.org/10.1080/02640410500189371

Prentice, W.E. (1994). *Rehabilitation techniques in sports medicine.* Mosby.

Roberts, J.M., & Wilson, K. (1999). Effects of stretching duration on active and passive range of motion in the lower extremity. *British Journal of Sports Medicine*, *33*(4), 259-263. https://doi.org/10.1136/bjsm.33.4.259

Robles-Palazón, F.J., Ayala, F., Cejudo, A., De Ste Croix, M., Sainz de Baranda, P., & Santonja, F. (2022). Effects of age and maturation on lower extremity range of motion in male youth soccer players. *Journal of Strength and Conditioning Research*, *36*(5), 1417-1425. https://doi.org/10.1519/JSC.0000000000003642

Sands, W.A., McNeal, J.R., Penitente, G., Murray, S.R., Nassar, L., Jemni, M., Mizuguchi, S., & Stone, M.H. (2016b). Stretching the spines of gymnasts: A review. *Sports Medicine*, *46*(3), 315-327. https://doi.org/10.1007/s40279-015-0424-6

Santos, A.B., Lemos, M.E., Lebre, E., & Carvalho, L.A. (2015). Active and passive lower limb flexibility in high level rhythmic gymnastics. *Science of Gymnastics Journal*, *7*(2), 55-66.

Silva, C.C., Silva, L.F., Santos, C.R., Goldberg, T.B.L., Ramos, S.P., & Venancio, E.J. (2019). Genetic polymorphism on the flexibility of elite rhythmic gymnasts: State of art. *Apunts Medicina de l'Esport*, 54(201), 27-35. https://doi.org/10.1016/j.apunts.2018.10.001

Tanner, J.M. (1987). Issues and advances in adolescent growth and development. *Journal of Adolescent Health Care*, *8*(6), 470-478. https://doi.org/10.1016/0197-0070(87)90048-9

Uzunov, V. (2008). Stretching scientifically. Part II: The pros and cons to modern methods. *Gym Coach*, *2*, 6-14.

Vernetta, M., Peláez-Barrios, E.M., & López-Bedoya, J. (2020). Systematic review of flexibility tests in gymnastics. *Journal of Human Sport and Exercise*, *17*(1), 1-16. https://doi.org/10.14198/JHSE.2022.171.07

Submitted: January 9, 2024
Accepted: July 22, 2024
Published Online First: December 9, 2024

Correspondence to:
Elena Milenković
University of Zagreb, Faculty of Kinesiology
Horvaćanski zavoj 15, Zagreb, Croatia
E-mail: elenamilenkovic6@gmail.com

THE EFFECTS OF VERTICAL JUMP AND SPRINT FATIGUE ON WHOLE-BODY BIOMECHANICS

Eric M. Mosier[1], Andrew C. Fry[2], Justin X. Nicoll[3], Stephanie A. Sontag[4], Dimitrije Cabarkapa[2], and Rhonda C. Beemer[5]

[1]Exercise Science Laboratory, Kinesiology Department, Washburn, University, Topeka, KS, USA
[2]Jayhawk Athletic Performance Laboratory – Wu Tsai Human Performance Alliance, University of Kansas, Lawrence, KS, USA
[3]Department of Kinesiology, California State University, Northridge, CA, USA
[4]Applied Neuromuscular Physiology Laboratory, Oklahoma State University, Stillwater, OK, USA
[5]Human Performance Laboratory, School of Health Science and Wellness, Northwest Missouri State University, Maryville, MO, USA

Original scientific paper
DOI: 10.26582/k.56.2.6

Abstract:

This study compared the kinetic and kinematic variables measured by a three-dimensional markerless motion capture system (MCS) to identify alterations in lower-extremity performance following vertical jump (VJ) and sprint anaerobic fatiguing tasks. Eleven females ($\bar{X}$±SD; 20.8±1.1 years, 72.2±7.4 cm, 68.0±7.2 kg) and eleven males (23.0±2.6 years., 180.3±4.8 cm, 80.4±7.3 kg) volunteered to participate in the present investigation. Participants were screened using the Functional Motion Analysis (FMA) protocol, consisting of 19 full-body motions, from which algorithm-derived scores were calculated [i.e., composite, power, functional strength, dysfunction, vulnerability, and exercise readiness score (ERS)] pre- and post-fatiguing tests. Each participant completed one familiarization session and three randomized acute fatiguing protocols [i.e., control, repeated vertical jump test (RVJT), 25-second resisted sprint test]. The repeated measures MANOVA indicated a statistically significant three-way interaction (score x condition x time). Follow-up analyses indicated differences between pre- and post-tests in composite score (1556.43±307.8; 1368.00±264.62), power score (813.34±242.39; 687.32±164.83), and ERS (18.16±4.75; 16.02±3.54) during the RVJT experimental sessions, respectively. The FMA scores suggested decrements in performance are first observed in the decreases in power production during high velocity movements (i.e., RVJTs), and the viability of a MCS to evaluate biomechanical alterations following fatiguing tasks.

Key words: *kinetics, kinematics, markerless motion capture, performance*

Introduction

Technology and motion capture systems (MCS) have experienced growth over the past few decades. These improvements have led to analytical tools that allow detailed analyses of the counter-movement vertical jump (CMVJ), and to determine the vertical displacement of the center of mass (COM) (Feltner, Bishop, & Perez, 2004; Feltner, Fraschetti, & Crisp, 1999; Hara, Shibayama, Takashita, Hay, and Fukashiro, 2008; Lees, Vanrenterghem, & Clercq, 2004). These devices have been used to assess an individual's upper- and lower-body motions, both explosive and functional in nature. Furthermore, a MCS allows derivation of the individual joint torques and ground reaction forces (GRF) produced. Markerless MCS quantifies the kinetic and kinematic movements of body segments and joints that influence the forces generated, and the enhancement of performance during a CMVJ with an arm swing (Fry, Herda, Sterczala, Cooper, & Andre, 2016; Mosier, Fry, & Lane, 2019; Perrott, Pizzari, Cook, & McClelland, 2017), or biomechanical alterations following anaerobic fatiguing tasks (i.e., vertical jump and resisted sprints) (Mosier, 2018). For example, Cabarkapa, Fry, and Mosier (2020) reported strong agreement in peak force and power for a basketball dunking motion between markerless MCS and a uni-axial force plate as a criterion measure. These advancements in MCS and screening protocols can be used to identify athletes at risk when performing various types of sport-specific movements. One published study by Mosier, Fry, Moodie, Moodie, and Nicoll, (2018) demonstrated the capability of a markerless MCS of identifying high-risk for non-contact season-ending injuries among American football athletes.

There are a wide variety of anaerobic tests that incorporate different modes of exercise or movement patterns, which also vary in duration, in order to test the anaerobic capacity of athletes. Repeated jumps and sprinting protocols are becoming more prevalent for assessing athletes' anaerobic power and capacity. The Bosco test is a popular test consisting of repeated jumps, in which an athlete performs continuous vertical jumps (VJ) for a specific duration (typically 60 sec) (Bosco, Luhtanen, & Komi, 1983; McNeal, Sands, & Stone, 2010). The jump test was reported to be suitable to evaluate the power output of leg extensor muscle during natural motion (Bosco, et al., 1983). Currently, the Wingate anaerobic test on a cycle ergometer is the most used and reported anaerobic performance test (Bar-Or, 1987; Inbar, Bar-Or, & Skinner, 1996; McLain, Wright, Camic, Kovacs, Hegge, and Brice, 2015). However, several sports that incorporate running may result in a more accurate anaerobic performance test assessment. McLain et al. (2015) indicated the non-motorized treadmill (NMT) (typically 25 sec with resistance of 18% of body weight) offers a suitable tool for the assessment of all-out sprint performance, thus providing an athlete with the ability to exert peak anaerobic power and measure anaerobic capacity.

Athletes often become fatigued during athletic events and anaerobic or aerobic performance assessments. With the onset of athletic fatigue, reaction times to external stimuli are delayed and injuries are more likely to occur (Chappell, et al., 2005). Fatigue is an intrinsic factor affecting the musculoskeletal and neurological systems (Benjaminse, et al., 2008; Chappell, et al., 2005). The system of fatigue can create an environment that increases the risk of non-contact injuries or more specifically anterior cruciate ligament (ACL) injuries by altering the lower extremity loading and landing strategies. ACL injuries are among the most common knee injuries observed in athletes (Agel, Olsen, Dick, Arendt, Marshall, & Sikka, 2007; Arendt, Agel, & Dick, 1999; Dick, Putukian, Agel, Evans, & Marshall, 2007; Mihata, Beutler, & Boden, 2006). Non-contact ACL injuries are common in team sports such as soccer, basketball, field hockey, and volleyball (Agel, et al., 2007; Arendt, et al., 1999; Dick, et al., 2007; Mihata, et al., 2006). As a result of the explosive and high fatiguing nature of these team sports, the muscular performance is notably impacted. The result of fatigue has been reported to decrease motor control performance (Johnston 3rd, Howard, Cawley, & Losse, 1998; Wojtys, Wylie, & Huston, 1996), increase knee joint laxity (Rozzi, Lephart, & Fu, 1999; Skinner, Wyatt, Stone, Hodgdon, & Barrack, 1986; Wojtys, et al., 1996), decrease balance skill (Johnston 3rd, et al., 1998), and decrease proprioception (Hiemstra, Lo, & Fowler, 2001; Lattanzio & Petrella, 1998; Lattanizio, Petrella, Sproule, & Fowler, 1997; Miura, et al., 2004; Rozzi, et al., 1999). With the onset of fatigue, the capacity of muscle fibers to absorb energy decrease and neuromuscular function alters, which has been shown to increase anterior tibial transition (Rozzi, Lephart, Gear, & Fu, 1999; Skinner, Wyatt, Hodgdon, Conard, & Barrack, 1986). These effects indicate a decreased capacity for controlling body movement and may indicate fatigue as a contributor to non-contact ACL injuries (Benjaminse, et al., 2008; Hiemstra, et al., 2001; Nyland, Shapiro, Caborn, Nitz, & Malone, 1997; Rodacki, Fowler, & Bennett, 2001). Chappell et al. (2005) suggested that vertical jump and sprint fatiguing protocols caused subjects to land with increased proximal tibia peak anterior shear force and decreased knee flexion at the time that peak anterior sheer force occurs (Pappas, Scheikhzadeh, Hagins, & Nordin, 2007). Similarly, muscle fatigue has been shown to alter the lower extremity biomechanics of healthy individuals (Nyland, et al., 1997; Pinniger, Steele, & Groeller, 2000). Madigan and Pidcoe (2003) assessed the effects of lower extremity muscle fatigue on drop-landing biomechanics and documented an increase in performance at the hip to compensate for the weakness created in the thigh muscles. Furthermore, Bishop et al. (2022) recently reported the usage of countermovement vertical jump for performance assessments, monitoring of neuromuscular fatigue, and a part of a test battery for return to performance among injured athletes. Further evaluation of the biomechanical changes during performances will give future insight into how fatigue can be rated and how to prevent fatigue-related injuries.

Therefore, the aim of the present study was to examine the acute whole-body biomechanical alterations following vertical jump and sprint anaerobic fatiguing tasks using functional motion analysis (FMA) screening scores. It was hypothesized that an innovative three-dimensional (3D) markerless MCS would detect and determine biomechanical alterations following fatiguing tasks. In addition, it was also hypothesized that both the VJ fatiguing and sprint fatiguing tasks would cause acute biomechanical alterations specifically to the lower-body extremities. Understanding acute whole-body biomechanical fatigue may further provide information for understanding when an athlete begins altering mechanics to sustain performance.

Methods

Study sample

Eleven healthy, recreationally active females ($\bar{X}$±SD); age=20.8±1.1 years, height=172.2±7.4 cm, body mass=68.0±7.2 kg), and eleven healthy, recreationally active males (age=23.0±2.6 years, height=180.3±4.8 cm, body mass=80.4±7.3 kg) volunteered to participate in the present investigation.

All participants were physically active for a minimum of one hour for three days a week for at least the preceding three months. None of the participants reported a history of current or prior neuromuscular diseases or musculoskeletal injuries specific to the ankle, knee, or hip joints. Participants demonstrated functional range of motion in hip, knee, ankle, and shoulder joints without limiting mechanical motion and performance during squats, VJ, and running tasks. This study was approved by the University's institutional review board for human subjects' research. Each subject read and signed an informed consent form and completed a health history questionnaire prior to participating.

Study design

Each participant visited the laboratory four times: for one familiarization session, one control session, and two experimental sessions. The familiarization consisted of informed consents signing, VJ and sprint screening, a warm-up protocol, practice low intensity fatiguing protocols, and completion of the FMA. During the experimental session, participants completed a 10-min standardized warm-up protocol followed by performing the pre-test FMA, starting with the jump motions, followed by the squat motions, and then the remaining motions. The participants preformed one of the three randomized acute anaerobic fatiguing protocols [i.e., control session, repeated vertical jump test (RVJT), 25-second sprint test] followed by the post-test FMA (Figure 1). Each participant completed one session per week at the same time of day. The laboratory temperature (24-28°C) and humidity (38-42%) remained within a consistent range.

Functional motion analysis (FMA)

The FMA is a collection of 19 different motions to assess an individual's upper extremity and lower extremity functioning using the 3D markerless MCS. The motions include shoulder ranges of motion (ROM) (i.e., shoulder abduction and adduction, shoulder horizontal abduction, shoulder internal and external rotation, shoulder flexion and extension), trunk rotation, bilateral overhead squat, right and left leg unilateral squat, right and left leg lunge, right and left leg 20-sec balance test, bilateral CMVJ, right and left unilateral CMVJ, concentric VJ, five right leg and five left leg VJs, and depth jump. All nineteen motions are incorporated into the FMA report. Cabarkapa, D., Cabarkapa, D.V., Philipp, Downey, and Fry (2022) recently examined the reliability of FMA scores and determined good to excellent reliability across multiple sessions (i.e., two sets of three FMA separated one week apart; six in total).

The motions that were believed to be most affected by the acute fatigue were tested first; thus, the jump motions first, followed by the squat motions, and the remaining motions. The order of the FMA during the experimental sessions was the following: bilateral CMVJ, right and left unilateral CMVJ, concentric VJ, five right leg and five left leg VJs, and depth jump, bilateral overhead squat, right and left leg unilateral squat, right and left leg lunge, right and left leg 20-sec balance test, shoulder abduction and adduction, shoulder horizontal abduction, shoulder internal and external rotation, shoulder flexion and extension, and trunk rotation.

Functional motion analysis scores

The nineteen motions of the FMA were used to calculate six different performance scores focusing on certain movement variables. These scores were: the composite score, power score, strength score, dysfunction score, exercise readiness score, and vulnerability score. The composite score is a cumulative score based on the overall performance (power score + functional strength score – dysfunction score). The power score consists of data from jump heights and is an aggregate of all the jump performances. The functional strength score is the accumulation of squat depths and is an aggregate of all the squat performances. The dysfunction score consists of asymmetries (upper limb, lower limb, and trunk), knee valgus, lower limb kinetic chaining, and balance performances. The exercise readiness score (ERS) is a scale that depicts the level of training and readiness. The score consists of three factors: rebalance, development, and optimization. The rebalance phase is a range from removal of compensations towards biomechanical symmetry between the right and left upper and lower extremi-

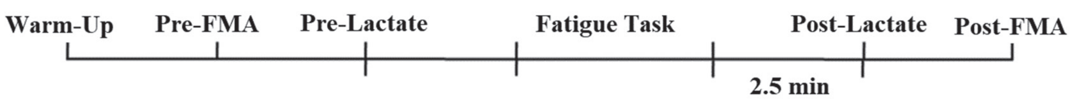


Figure 1. The timeline that was conducted for the experimental sessions [repeated vertical jump test (RVJT), sprint, control].

ties. All consisting of unilateral forces, joint flexions, and joint torques. The development phase is the evaluation of an individual's biomechanics towards kinetic and kinematic symmetry. The optimization phase is the maintenance of an individual's biomechanics and displaying peak performance mechanics. The vulnerability score is the aggregate of all performance, including stresses (consisting of unilateral high forces, joint flexions and joint torques), and compensation patterns (overuse of dominant side or limited usage due to history of an injury). This score is presented as a percentage of 0-100%. Cabarkapa, Caparkapa, et al. (2022) reported no statistically significant differences between algorithm based FMA scores from the markerless MCS indicating good to excellent reliability. Excellent reliability measurements were reported for readiness scores, good-to-excellent for functional strength and power scores, and moderate-to-excellent for dysfunction (Cabarkapa, Cabarkapa, et al., 2022), thus indicating the usage of the markerless MCS for the assessment of various types of biomechanical parameters.

Acute fatigue protocols

Warm-up protocol. Each participant was instructed through a 10-min dynamic warm-up at the beginning of each experimental session. The warm-up consisted, in the order, of ten quadriceps pull to single leg Romanian deadlift reaches, ten tin soldiers, ten figure fours, ten walking lunges with a T-spine, five inchworms, forward skips with forward arm circles, backward skips with backward arm circles, forward skips with hip internal rotation, backward skips with hip external rotation, A-skips, A-skips to squat, and ten body-weight squats.

Control session. Each participant was instructed to sit for 15 min. The FMA was completed before the rest period in order of the jump motions, followed by squat motions, and remaining FMA motions. The FMA was completed by the blood samples taking, which were collected for lactate determination pre- and 2.5-min post-control period. Heart rate was collected with the chest strap (Polar FT1, Bethpage, NY, USA) throughout the entire session.

Repeated vertical jump test. During the repeated vertical jump test (RVJT), the participant was instructed to bend the knee to about 90 degrees and jump explosively, then repeat immediately on landing for one set (15 sec jumping, 15 sec rest, 15 sec jumping, 15 sec rest) lasting one minute in duration. Each participant completed five sets (5 min). The FMA was completed before the RVJT. This fatigue test was determined based on accumulated blood lactate responses during pilot investigation completed in our laboratory. Investigations during pilot testing comparing RVJT and Bosco 60-sec jump test resulted in greater blood lactate concentrations and post heart rate for RVJT. Heart rate was collected throughout the entire experimental sessions but was only reported pre- and post-test.

25-second sprint test. Each participant was attached to the resistive harness of a NMT (Woodway Force 3.0 treadmill, Waukesha, WI, USA), which was set to a resistance equal to 18% of the participant's body weight. Participants carried out a 25-sec maximal sprint on the Woodway NMT treadmill (McLain, et al., 2015). Heart rate was collected throughout the entire experimental sessions but was only reported pre- and post-test.

Blood samples

Each participant gave three minimal blood samples (approximately one drop) at each testing session (baseline, pre, and post) by way of a lancet finger stick. Fingertip samples were collected into a lactate testing strip for analysis via a Lactate Plus handheld blood lactate analyzer (Nova Biomedical, Waltham, MA, USA). Baseline samples were collected following the warm-up protocol immediately prior to the pre-FMA. In addition, samples were collected before the randomized experimental and 2.5-min post experimental tests before the post-test FMA.

Heart rate

Heart rate was collected with a chest monitor strap (Polar FT7, Polar Electro Inc., Bethpage, NY). Heart rate was collected throughout the entire experimental sessions; however, it was only reported pre-test and immediately post-test.

Performance tests

Motion capture device. During each FMA motion performance, the kinetic and kinematic variables were collected and analyzed using the DARI (DARI Motion, Overland Park, KS, USA) 3D markerless MCS system. Anthropometric estimates (Winter, 1990) were used to estimate the segmental center of mass (COM)s. In addition, full-body GRFs and extremity joint kinematics were assessed. The 3D MCS has been shown to validly measure full-body and segmental kinetics and kinematics without a force plate or video, thus providing accurate performance measures (Fry, et al., 2016; Perrott, et al., 2017). In addition, MCS has been used to determine the contribution of the upper extremities during a CMVJ (Mosier, et al., 2019), and moderate-to-strong correlations were reported between FMA scores (i.e., readiness, functional strength, power) and traditional health-related physical fitness parameters such as estimated VO_{2max} and body fat percentage (Cabarkapa, Whetstone, et al., 2022). Body fat percentage showed a weak positive correlation with vulnerability and moderate-to-strong positive correlation with ERS, power, and functional strength scores. VO_{2max} showed a weak negative correlation with vulnerability and moderate-to-strong positive correlation with ERS, power, and functional strength scores, thus further indicating that MCS performance scores may be used as a non-invasive testing alternative or in conjunction with currently implemented traditional testing modalities (Cabarkapa, Whetstone, et al., 2022).

Force plate device. During each squat and jump motion, the kinetic variables were collected and analyzed using a uni-axial force plate (Rice Lake Weighing Systems, Rice Lake, WI, USA) through a data acquisition system (Biopac MP 150 System, Goleta, CA, USA) sampling at 1000 Hz to monitor the GRF. In addition, the RVJT was collected and analyzed to determine flight time and positive impulse with a sampling rate of 1000 Hz.

Non-motorized treadmill. During the 25-sec sprint test, the kinetic variables were collected on the NMT (Woodway Force 3.0 treadmill, Waukesha, WI, USA), which was set to a resistance equal to 18% of the participant's body weight (McLain, et al., 2015).

Statistical analyses

Statistical analyses were conducted for the performance measures with a factorial repeated measures MANOVA using the FMA scores (composite score, power score, functional strength score, dysfunction score, exercise readiness score, and vulnerability score) x conditions (RVJT, sprint, CON) x time (pre-test, post-test) x sex (females, males). A Pearson correlation matrix was used to compare the relationship between each of the FMA scores during the familiarization session. Two separate 2-way repeated measures (RM) ANOVAs were used to examine the differences in HR [condition (RVJT, sprint, CON) x time (pre-test, post-test)] and in accumulated blood lactate [condition (RVJT, sprint, CON) x time (pre-test, 2.5-min post-test)]. Paired samples *t*-tests were used to examine the differences in flight times and positive impulses of the second jump of set one and last jump of set five during the RVJT. These VJs were selected to include the VJ rebound and the next CMVJ. *Post-hoc* comparisons were conducted when needed using the Bonferroni correction. The level of significance was set *a priori* at $p \leq .05$ for the statistical tests. Statistical analyses were performed using SPSS 24 (IBM Corporation, Amonk, New York, USA) and Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA).

Results

Table 1 lists the descriptive statistics (mean and standard deviations ($\bar{X} \pm$ SD) and pre- and post-test significance levels for the FMA scores for each pre-test and post-test during each condition. The Pearson correlations matrix (Table 2) indicated moderate to strong correlations between the FMA scores, indicating the scores should be analyzed via a MANOVA (score x condition x time x sex). The MANOVA indicated a three-way interaction (score x condition x time) (p=.01). Follow-up analyses indicated significant differences between pre- and post-tests for the composite score (p<.01), power score (p<.01), and ERS (p<.01) during the RVJT experimental sessions.

Table 3 lists the HR during the pre- and post-tests, and accumulated blood lactate during the

Table 1. Reporting Motion Capture System (MCS) composite, power, functional strength, dysfunction, vulnerability, and exercise readiness scores in the pre- and post-test during the repeated vertical jump (RVJT), spring, and control (CON) experimental sessions

Condition	Sex	MCS composite	Power score	Functional strength score	Dysfunction score	Vulnerability score	Exercise readiness score
Pre-RVJT	F	1387.2 ± 184.6	665.6 ± 86.0	830.6 ± 97.4	108.8 ± 48.8	40.9 ± 10.1	16.0 ± 2.3
	M	1839.2 ± 159.4†	1015.3 ± 132.0†	949.7 ± 83.1†	126.0 ± 32.3	37.0 ± 8.0	21.7 ± 2.3†
Post-RVJT	F	1217.9 ± 166.9*	585.5 ± 45.1	779.2 ± 113.0	146.7 ± 60.8	46.7 ± 11.0	13.8 ± 1.6*
	M	1518.1 ± 264.1*†	789.2 ± 173.6*†	883.6 ± 101.8*†	163.7 ± 73.5	42.6 ± 13.4	18.2 ± 3.6*†
Pre-sprint	F	1414.8 ± 212.1	691.1 ± 95.4	840.5 ± 101.5	116.7 ± 37.1	39.9 ± 7.1	16.4 ± 2.2
	M	1804.0 ± 143.0†	999.0 ± 126.1†	928.3 ± 107.4	123.2 ± 56.6	37.6 ± 9.1	21.0 ± 2.3†
Post-sprint	F	1365.9 ± 170.1	633.8 ± 82.2	838.6 ± 85.4	164.5 ± 203.2	41.6 ± 7.3	15.4 ± 1.9
	M	1662.8 ± 221.9†	889.9 ± 155.2*†	907.4 ± 114.8	131.6 ± 48.0	37.8 ± 10.9	20.2 ± 2.8†
Pre- CON	F	1387.3 ± 210.1	655.3 ± 106.3	834.6 ± 85.4	102.6 ± 44.5	40.6 ± 9.0	15.7 ± 2.6
	M	1799.7 ± 145.6†	965.1 ± 138.2†	948.7 ± 100.4†	114.2 ± 51.9	37.4 ± 10.2	21.3 ± 2.2†
Post-CON	F	1354.7 ± 210.1	643.5 ± 121.1	823.9 ± 100.4	112.5 ± 46.7	41.1 ± 8.7	15.3 ± 2.9
	M	1676.4 ± 276.9†	918.0 ± 160.2†	806.1 ± 307.5	126.5 ± 51.3	39.0 ± 14.3	20.1 ± 3.5†

Note. Mean ± SD for reported scores for females (F) and males (M). MANOVA indicates significant differences between score x condition x time (p<.01). * indicates significant differences between the pre- to post-FMA tests. † indicates significant differences between females and males (p<.05).

Table 2. Pearson correlation matrix among the reported performance scores during the familiarization session

	Power score	Functional strength score	Dysfunction score	Vulnerability score	Exercise readiness score
MCS composite score	0.90*	0.78*	-0.41	-0.26	0.92*
Power score	----	0.47*	-0.12	-0.18	0.89*
Functional strength score	----	----	-0.39	-0.42	0.64*
Dysfunction score	----	----	----	0.64*	-0.33
Vulnerability score	----	----	----	----	-0.47*
Exercise readiness score	----	----	----	----	----

Note. n=22; *correlation indicates significance (p<.05)

Table 3. Heart rate and accumulated blood lactate changes during multiple time points throughout the repeated vertical jump test (RVJT), sprint, and control (CON) sessions

		Heart rate (bpm)		Accumulated lactate (mmol/L)	
Condition	Sex	Pre-test	Post-test	Pre-test	2.5 min post-test
RVJT	F	80.9 ± 15.5	183.9 ± 12.8*†	2.6 ± 1.7	11.2 ± 2.4*†
	M	69.9 ± 10.5	171.2 ± 23.9*†	2.1 ± 1.2	13.6 ± 1.8*†
Sprint	F	79.3 ± 18.9	168.5 ± 30.8*†	2.5 ± 1.6	10.7 ± 2.0*†
	M	75.1 ± 10.0	176.6 ± 8.8*†	3.3 ± 3.0	14.8 ± 3.0*†
CON	F	75.4 ± 18.9	74.7 ± 6.4	1.7 ± 0.5	3.1 ± 2.9
	M	81.6 ± 17.0	86.7 ± 11.9	3.2 ± 2.5	2.3 ± 2.2

Note. Heart rate and change in accumulated blood lactate for females (F) and males (M). * indicates significant differences between the pre- to post-test, † indicates significant differences from the control (p<.05).

Table 4. Vertical jump performances $\bar{X} \pm SD$ for females (F) and males (M) during the repeated vertical jump test (RVJT) during the first and jumping last set

	Set 1			Set 5				
	Jump 2 of Set 1			Last jump of Set 5				
Sex	# of jumps	Flight time (ms)	Positive impulse (N·sec)	# of jumps	Flight time (ms)	Positive impulse (N·sec)	Change in flight time (%)	Change in positive impulse (%)
F	13.0 ± 1.0	0.4 ± 0.1	250.0 ± 48.5	13.0 ± 1.0	0.3 ± 0.0*	161.5 ± 52.8*	-33.7 ± 12.7	-33.8 ± 20.4
M	14.0 ± 1.0	0.5 ± 0.0	381.4 ± 46.5	13.0 ± 1.0	0.3 ± 0.1*	204.1 ± 80.5*	-41.8 ± 9.7	-46.2 ± 20.6

Note. Females (F), Males (M). * indicates significant differences between set 1 and set 5, (p<.05). Change in flight time and positive impulse during the selected vertical jump.

Table 5. Sprint performance $\bar{X} \pm SD$ of females (F) and males (M) during the 25-sec non-motorized resisted sprint test

Sex	Distance (m)	Mean sum force (N)	Mean power (W)	Peak power (W)	Change in power (%)	Mean velocity (m/s)	Peak velocity (m/s)	Change in velocity (%)
F	70.2 ± 7.5	155.4 ± 15.9	400.4 ± 76.2	1577.1 ± 316.4	-47.4 ± 12.2	2.8 ± 0.3	3.5 ± 0.5	-24.3 ± 6.8
M	94.7 ± 8.0	190.2 ± 17.1	716.3 ± 114.7	2825.2 ± 439.9	-66.2 ± 11.0	3.8 ± 0.3	5.1 ± 0.6	-33.9 ± 10.8

Note. Mean sum force is the sum of horizontal and vertical forces; mean power and mean velocity is the average across the 25-sec sprint; peak power and peak velocity is the maximum value across the 25-sec sprint; change in power and change in velocity is the difference between the maximum peak to the last foot stride peak represented as a percent.

pre-test and 2.5-min post-tests. A 2-way ANOVA indicated a significant interaction for HR (condition x time) (p<.01). Follow-up analysis indicated the post-test HR was significantly greater than pre-tests (p<.01). Furthermore, the RVJT (p<.01) and sprint (p<.01) conditions were significantly greater compared to the CON during the post-tests. In addition, a 2-way RM ANOVA indicated a significant interaction for accumulated blood lactate (condition x time) (p<.01) (Table 3). Follow-up analysis indicated post-test lactate accumulation was significantly greater compared to the pre-tests (p<.01), and the RVJT and sprint conditions were significantly greater than the CON (p<.01).

Table 4 lists the number of jumps, flight time, and positive impulse of set one and set five during the RVJT. The paired samples *t*-tests indicated the flight time (p<.01) and positive impulse (p<.01) during the last vertical jump during set five were significantly less than the second jump of set one for both males and females (Table 4). Table 5 lists the force, velocity, and power during the 25-sec NMT treadmill sprint tests. The reduction in the FMA performance scores (pre-test vs. post-test) indicated females and males exhibited a reduction in power and velocity following the sprint test. Table 6 lists the fatigue rates for each FMA score per condition. The fatigue scores indicated the greatest reduction in the composite score, power score, and ERS, during the RVJT session.

Discussion and conclusion

The notion that fatigue is a predisposing factor responsible for the increased number of musculoskeletal injuries is common in sports indicating the importance of pre-exercise screening and onset of fatigue screening in athletes. The current investigation determined that an innovative 3D MCS was capable of detecting acute lower-body biomechanical changes due to acute fatigue. The MANOVA indicated a three-way interaction (score x condition x time) (p=.01). Further analysis of the FMA scores indicated alterations of performance occurred following the RVJT. The significant decrease in the power score can account for the reduction in the composite score due to the calculation of the composite score (composite score = power score + functional strength score – dysfunction score). In addition, the power score is an aggregate of the VJ measurements. As a result, the bilateral CMVJ VJH decreased five centimeters from pre- to post-RVJT [pre-RVJT (48.5±15.0 cm), post-RVJT (43.2±9.4 cm)]. Further examination can account for reduction in the power score due to the decrease in the power and velocity, as a result of the onset of fatigue following the RVJT. This decrease in power and velocity can further be explained by the reduction in VJH. Although significant changes were not observed for the functional strength scores, this can be explained by the measurements of the score which is an aggregate of all squat and lower-limb motions. Although there was an onset of muscle fatigue, the squat motion mechanics were not affected by the fatiguing tasks. The differences in the power and functional strength scores further indicate that high power and velocity movements are the first to falter and are most susceptible to fatigue. Fry et al. (1994) has indicated that strength is maintained unless the fatigue stimulus is extended for a longer duration. The significant decrease in the ERS following the RVJT indicates a change in one of the three categories (rebalance, develop, optimization) used in determining ERS. It is speculated the decrease in ERS is a result of the decrease in the optimization score due to the acute decrease in the velocity and power performance. The optimization score is the performance phase in which individuals can display the foundation of simple and complex mechanics by providing maintenance of biomechanics and displaying peak performance.

There were no changes in either the vulnerability score or the dysfunction score further suggesting that these measures are more stable scores. Furthermore, the acute RVJT fatigue did not significantly affect the asymmetry, kinetic chaining, compensation, or balance performances. The 4-way MANOVA did not report an interaction for sex. Further examination indicated that, although the performance scores varied between sex, males and females responded in a similar manner from pre- to post-tests.

The FMA fatigue rates (comparison of pre-test versus post-test mean scores) indicate the greatest reduction in performance among the FMA scores from pre- to post-test for each condition (Table 6). The greatest decrease in performance was indicated by the composite score, power score, and ERS. Furthermore, the greatest decrease in FMA scores were observed during the RVJT. No changes were

Table 6. Reported the fatigue rates $\bar{X} \pm SD$ for the MCS composite, power, functional strength, dysfunction, vulnerability, and exercise readiness scores during the repeated vertical jump (RVJT), sprint, and control (CON) experimental session

Condition	Sex	MCS composite score	Power score	Functional strength score	Dysfunction score	Vulnerability score	Exercise readiness score
RVJT	F	-11.9 ± 8.1	-11.40± 9.2	-6.2 ± 8.3	57.9 ± 96.7	17.2 ± 23.4	-12.6 ± 8.9
	M	-17.7 ± 10.1	-22.7 ± 11.1	-7.0 ± 5.6	46.0 ± 94.4	21.4 ± 47.4	-16.2 ± 11.8
Sprint	F	-3.0 ± 5.2	-8.0 ± 7.2	-0.1 ± 6.8	48.7 ± 170.4	5.3 ± 18.3	-6.0 ± 6.3
	M	-7.7 ± 10.9	-10.6 ± 13.5	-1.9 ± 9.6	20.7 ± 52.0	2.7 ± 23.9	-3.6 ± 12.6
CON	F	- 2.3 ± 10.0	-1.0 ± 17.7	-1.3 ± 5.5	26.6 ± 80.5	4.0 ± 23.4	-2.1 ± 13.5
	M	-7.1 ± 11.3	-5.2 ± 3.9	-15.1 ± 31.6	25.4 ± 62.7	3.6 ± 15.5	-6.1 ± 10.0

Note. Fatigue rate is the difference between the pre- and post-score as a percent of mean change across participants.

observed in the dysfunction score and vulnerability score, further indicating these are stable scores as previously stated (Cabarkapa, Cabarkapa, et al., 2022).

The significant increases in accumulated lactate from pre- to 2.5-min post-test indicate that the RVJT and resisted sprint tests involved anaerobic glycolytic fatigue. In addition, both acute fatiguing tasks were significantly different from the CON session. Similar accumulated lactate responses for pre- to post-tests were observed for both fatiguing sessions. Previous research has indicated blood lactate reaching 15.4 mmol/L following a Wingate test and 8.1 mmol/L following the Bosco 60-sec jump test (Bosco, et al., 1983). Both measurements were collected 5-min post-fatigue exercise. In comparison, the RVJT post-test accumulated of 12.4 mmol/L 2.5 minutes post-test indicated the task was more anaerobically demanding than what was previously reported for the Bosco 60-sec jump test due to the duration and production of work during the fatiguing task. McLain et al. (2015) reported accumulated lactate of 15.8 mmol/L 5 minutes following the 25-sec resistance sprint. The current investigation reported accumulated lactate of 14.5 mmol/L 2.5 minutes post-test. The measurement of accumulated lactate levels 2.5-min post-fatigue test was done to prevent excessive recovery from affecting the biomechanical assessment during the post-FMA test. The time in which the blood lactate concentration was drawn post-fatigue test occurred before the peak blood lactate concentration (5 min) and the duration reported (Weltman, 1995). Blood lactate concentration collection at 2.5-min post only prevented the collection of the peak blood lactate concentration which would be observed at 5 minutes post exercise (Weltman, 1995). Furthermore, accumulated blood lactate indicated that these fatigue tests still indicated similar anaerobic fatigue responses and also suggested that these fatigue tests were performed with maximal effort. Maximal HR has not been reported by the Bosco jump test, RVJT, or the resisted sprint test. It is speculated HR will reflect elevation trends similar to the elevations in the accumulated blood lactate.

Similar decreases were observed in performance comparing the flight times and the positive impulse during the repeated jump test. Previous literature has reported that both a longer flight time or great positive impulse have indicated a higher VJH (Moir, 2008). Both the flight time and the positive impulse of the 2nd VJ of set one to the last VJ indicated a significant decrease in performance during the RVJT. Equal numbers of VJs per set were performed by both males and females. Therefore, individuals spent more time on the ground than in the air as participants fatigued, furthermore, performing the vertical jump of poor quality. Previous literature has reported similar decreases in velocity and power during the 25-sec sprint test (McLain, et al., 2015). A greater fatigue rate/index (% change) was indicated for the repeated jump test (i.e., flight times, positive impulses) and for the 25-sec resisted sprint test (power, velocity).

The maximal efforts exerted during the acute fatiguing tasks and the decrease in the FMA performance indicated that both the males and females presented an acute biomechanical fatigue. With the onset of athletic fatigue, reaction times to external stimuli are delayed and injuries are more likely to occur (Chappell, et al., 2005). Fatigue increases the risk of non-contact injuries by altering the lower extremity takeoff and landing strategies. Daggett, Witte, Cabarkapa, and Fry (2022) conducted markerless MCS assessments throughout an ACL reconstruction rehabilitation protocol. The MCS provided gradual improvements in functional strength and ERS throughout the 3-6 months post ACL reconstruction period (Daggett, et al., 2022), further emphasizing the importance of the individual-based assessment of return-to-play criteria.

As previously noted, athletes often become fatigued during athletic events and anaerobic or aerobic performances or training, thus, further increasing the probability of non-contact injuries. This risk of fatigue-related injury could potentially vary from a minor injury to a severe injury (i.e., season ending injury). Such injuries are more common in reactive team sports. As a result of the explosive and high fatiguing nature of these team sports, the muscular performance is notably impacted further impacting athletes' performance and success during a season. Depending on the likelihood of an injury and its severity, this would be affecting an athlete's performance, training, playing time, etc. In some cases, a higher seriousness of an injury may result in a season/career ending. Regardless of the significance of the injury, there is always a concern for the recovery rate and duration of recovery. Nonetheless, recognizing athletes' mechanical alterations in performance, which may occur either following acute bouts of fatigue or due to the longevity of a season, may provide further insight into injury prevention. It also provides an enhanced understanding of an athlete's success and durability during a season. Further evaluation of the biomechanical changes during performances will give future insight into how fatigue can be rated, which knowledge may contribute to injury prevention.

Biomechanical changes in motion performance are believed to decrease shock absorption and knee stabilization during landing. The human body is efficient at absorbing the shock of the GRFs during takeoff and landing of VJs. However, if the musculature surrounding the joints are not properly developed, maintained, or if they are fatigued, it may lead to ligament susceptibility and a chronic limitation (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010). This presents a limitation of the present investigation and provides one of the directions for future research (e.g., further examination of biomechanical alterations during sport-specific fatigue or chronic overreaching). Furthermore, evaluation of acute biomechanical fatigue rates may determine when an athlete is able to return to sport following rehabilitation or developed fatigue biomechanical alterations.

The current investigation may pose a few limitations due to the population sample size and the scope of the population in the current investigation. However, a statistical power test was calculated prior to the investigation resulting in an equal number of males and females who meet the qualifications. The current experimental research is of a randomized cross-over design, meaning that all participants completed all conditions in a randomized order. Further follow-up investigations are needed to examine larger samples sizes and different sample populations that would provide further insight into biomechanical alterations based on training status and competitive level.

In conclusion, the current findings of the present study demonstrated the viability of the MCS test to evaluate biomechanical alterations in performance due to the acute fatigue among recreationally trained males and females. Differences in FMA scores and performances following acute fatigue protocols indicated acute biomechanical alterations in the lower extremities, specifically following the RVJT. Similar fatigue indexes and physiological responses were reported for the RVJT and the 25-sec NMT sprint test. The pre- to post-test FMA scores indicated decrements in performance were first observed in the decreases in power production during high velocity movements (i.e., VJs), further indicated by the reduction in the pre-test to post-test vertical jump height (VJH). Further research is needed to examine the responses of different levels of athletes, responses to other fatiguing methods of different intensities and durations, acute and chronic fatigue such as during athletic seasons, and influences of fatigue on athletic performance. Further evaluation and understanding of biomechanical alterations during performance will provide future insight into how fatigue can be rated, thus contributing to fatigue-related injuries prevention. Non-invasive examination of athletic movements and biomechanical alterations following acute fatiguing protocols can be used to reduce injury risk. Further advancements in MCS technology and screening protocols may be capable of predicting increased risk of season-ending injuries.

References

Agel, J., Olson, D.E., Dick, R., Arendt, E.A., Marshall, S.W., & Sikka, R.S. (2007). Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *Journal of Athletic Training*, *42*(2), 202-210.

Arendt, E.A., Agel, J., & Dick, R. (1999). Anterior cruciate ligament injury patterns among collegiate men and women. *Journal of Athletic Training*, *34*(2), 86.

Bar-Or, O. (1987). The Wingate anaerobic test An update on methodology, reliability and validity. *Sports Medicine*, *4*(6), 381-394.

Benjaminse, A., Habu, A., Sell, T.C., Abt, J.P., Fu, F.H., Myers, J.B., & Lephart, S.M. (2008). Fatigue alters lower extremity kinematics during a single-leg stop-jump task. *Knee Surgery, Sports Traumatology, Arthroscopy*, *16*(4), 400-407. https://doi.org/10.1007/s00167-007-0432-7

Bishop, C., Jordan, M., Torres-Ronda, L., Loturco, I., Harry, J., Virgile, A., Mundy, P., Turner, A., & Comfort, P. (2022). Selecting metrics that matter: Comparing the use of the countermovement jump for performance profiling, neuromuscular fatigue monitoring, and injury rehabilitation testing. *Strength and Conditioning Journal*, 45(5), 545-553. doi: 10.1519/SSC.0000000000000772

Bosco, C., Luhtanen, P., & Komi, P.V. (1983). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupational Physiology*, *50*(2), 273-282. https://doi.org/10.1007/BF00422166

Brazen, D.M., Todd, M.K., Ambegaonkar, J.P., Wunderlich, R., & Peterson, C. (2010). The effect of fatigue on landing biomechanics in single-leg drop landings. *Clinical Journal of Sport Medicine*, *20*(4), 286-292. doi: 10.1097/JSM.0b013e3181e8f7dc

Cabarkapa, D., Cabarkapa, D.V., Philipp, N.M., Downey, G.G., & Fry, A.C. (2022). Repeatability of motion health screening scores acquired from a three-dimensional markerless motion capture system. *Journal of Functional Morphology and Kinesiology*, *7*(3), 65. https://doi.org/10.3390/jfmk7030065

Cabarkapa, D., Fry, A.C., & Mosier, E.M. (2020). Validity of 3-D markerless motion capture system for assessing basketball dunk kinetics—A case study. *Sport Journal*.

Cabarkapa, D., Whetstone, J.M., Patterson, A.M., Mosier, E.M., Cabarkapa, D.V., & Fry, A.C. (2022). Relationship between health-related physical fitness parameters and functional movement screening scores acquired from a three-dimensional markerless motion capture system. *International Journal of Environmental Research and Public Health*, *19*(8), 4551. https://doi.org/10.3390/ijerph19084551

Chappell, J.D., Herman, D.C., Knight, B.S., Kirkendall, D.T., Garrett, W.E., & Yu, B. (2005). Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. *American Journal of Sports Medicine*, *33*(7), 1022-1029. https://doi.org/10.1177/0363546504273047

Daggett, M.C., Witte, K.A., Cabarkapa, D., Cabarkapa, D.V., & Fry, A.C. (2022). Evidence-based data models for return-to-play criteria after anterior cruciate ligament reconstruction. *Healthcare*, *10*(5), 929. https://doi.org/10.3390/healthcare10050929

Dick, R., Putukian, M., Agel, J., Evans, T.A., & Marshall, S.W. (2007). Descriptive epidemiology of collegiate women's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2002–2003. *Journal of Athletic Training*, *42*(2), 278.

Feltner, M.E., Bishop, E.J., & Perez, C.M. (2004). Segmental and kinetic contributions in vertical jumps performed with and without an arm swing. *Research Quarterly for Exercise and Sport*, *75*(3), 216-230. https://doi.org/10.1080/02701367.2004.10609155

Feltner, M.E., Fraschetti, D.J., & Crisp, R.J. (1999). Upper extremity augmentation of lower extremity kinetics during countermovement vertical jumps. *Journal of Sports Sciences*, *17*(6), 449-466. https://doi.org/10.1080/026404199365768

Fry, A., Kraemer, W., Van Borselen, F., Lynch, J., Triplett, N., Koziris, L., & Fleck, S. (1994). Catecholamine responses to short-term high-intensity resistance exercise overtraining. *Journal of Applied Physiology*, *77*(2), 941-946. https://doi.org/10.1152/jappl.1994.77.2.941

Fry, A.C., Herda, T.J., Sterczala, A.J., Cooper, M.A., & Andre, M.J. (2016). Validation of a motion capture system for deriving accurate ground reaction forces without a force plate. *Big Data Analytics*, *1*(1), 11. https://doi.org/10.1186/s41044-016-0008-y

Hara, M., Shibayama, A., Takeshita, D., Hay, D.C., & Fukashiro, S. (2008). A comparison of the mechanical effect of arm swing and countermovement on the lower extremities in vertical jumping. *Human Movement Science*, *27*(4), 636-648. https://doi.org/10.1016/j.humov.2008.04.001

Hiemstra, L.A., Lo, I.K., & Fowler, P.J. (2001). Effect of fatigue on knee proprioception: implications for dynamic stabilization. *Journal of Orthopaedic and Sports Physical Therapy*, *31*(10), 598-605. https://www.jospt.org/doi/10.2519/jospt.2001.31.10.598

Inbar, O., Bar-Or, O., & Skinner, J.S. (1996). *The Wingate anaerobic test*. John Wiley & Sons.

Johnston 3rd, R., Howard, M.E., Cawley, P.W., & Losse, G.M. (1998). Effect of lower extremity muscular fatigue on motor control performance. *Medicine and Science in Sports and Exercise*, *30*(12), 1703-1707. https://doi.org/10.1097/00005768-199812000-00008

Lattanizio, P.-J., Petrella, R.J., Sproule, J.R., & Fowler, P.J. (1997). Effects of fatigue on knee proprioception. *Clinical Journal of Sport Medicine*, *7*(1), 22-27.

Lattanzio, P.J., & Petrella, R.J. (1998). Knee proprioception: A review of mechanisms, measurements, and implications of muscular fatigue. *Orthopedics*, *21*(4), 463-471. https://doi.org/10.3928/0147-7447-19980401-19

Lees, A., Vanrenterghem, J., & Clercq, D.D. (2004). Understanding how an arm swing enhances performance in the vertical jump. *Journal of Biomechanics*, *37*(12), 1929-1940. https://doi.org/10.1016/j.jbiomech.2004.02.021

Madigan, M.L., & Pidcoe, P.E. (2003). Changes in landing biomechanics during a fatiguing landing activity. *Journal of Electromyography and Kinesiology*, *13*(5), 491-498. https://doi.org/10.1016/S1050-6411(03)00037-3

McLain, T.A., Wright, G.A., Camic, C.L., Kovacs, A.J., Hegge, J.M., & Brice, G.A. (2015). Development of an anaerobic sprint running test using a nonmotorized treadmill. *The Journal of Strength and Conditioning Research*, *29*(8), 2197-2204. 10.1519/JSC.0000000000000854

McNeal, J.R., Sands, W.A., & Stone, M.H. (2010). Effects of fatigue on kinetic and kinematic variables during a 60-second repeated jumps test. *International Journal of Sports Physiology and Performance*, *5*(2), 218-229. https://doi.org/10.1123/ijspp.5.2.218

Mihata, L.C., Beutler, A.I., & Boden, B.P. (2006). Comparing the incidence of anterior cruciate ligament injury in collegiate lacrosse, soccer, and basketball players. *The American Journal of Sports Medicine*, *34*(6), 899-904. https://doi.org/10.1177/0363546505285582

Miura, K., Ishibashi, Y., Tsuda, E., Okamura, Y., Otsuka, H., & Toh, S. (2004). The effect of local and general fatigue on knee proprioception. *Arthroscopy: The Journal of Arthroscopic and Related Surgery*, *20*(4), 414-418. https://doi.org/10.1016/j.arthro.2004.01.007

Moir, G.L. (2008). Three different methods of calculating vertical jump height from force platform data in men and women. *Measurement in Physical Education and Exercise Science*, *12*(4), 207-218. https://doi.org/10.1080/10913670802349766

Mosier, E.M., Fry, A. C., & Lane, M.T. (2019). Kinetic contributions of the upper limbs during counter-movement vertical jumps with and without arm swing. *Journal of Strength and Conditioning Research*, 33(8), 2066-2073. doi: 10.1519/JSC.0000000000002275

Mosier, E. M. (2018). *The effects of vertical jump fatigue and sprint fatigue on total-body biomechanics.* (Doctoral dissertation, University of Kansas).

Mosier, E.M., Fry, A.C., Moodie, P.G., Moodie, N.G., & Nicoll, J.X. (2018). Movement analysis via motion capture systems help identify injury at-risk NCAA D1 football players—A preliminary study. Abstracts. *Journal of Strength and Conditioning Research*, 33(2), e3-e217, February 2019. | doi: 10.1519/JSC.0000000000002990

Nyland, J.A., Shapiro, R., Caborn, D.N., Nitz, A. J., & Malone, T.R. (1997). The effect of quadriceps femoris, hamstring, and placebo eccentric fatigue on knee and ankle dynamics during crossover cutting. *Journal of Orthopaedic and Sports Physical Therapy*, *25*(3), 171-184. https://www.jospt.org/doi/10.2519/jospt.1997.25.3.171

Pappas, E., Sheikhzadeh, A., Hagins, M., & Nordin, M. (2007). The effect of gender and fatigue on the biomechanics of bilateral landings from a jump: Peak values. *Journal of Sports Science and Medicine*, *6*(1), 77-84.

Perrott, M.A., Pizzari, T., Cook, J., & McClelland, J.A. (2017). Comparison of lower limb and trunk kinematics between markerless and marker-based motion capture systems. *Gait and Posture*, *52*, 57-61. https://doi.org/10.1016/j.gaitpost.2016.10.020

Pinniger, G.J., Steele, J.R., & Groeller, H. (2000). Does fatigue induced by repeated dynamic efforts affect hamstring muscle function? *Medicine and Science in Sports and Exercise*, *32*(3), 647-653.

Rodacki, A.L., Fowler, N.E., & Bennett, S.J. (2001). Multi-segment coordination: Fatigue effects. *Medicine and Science in Sports and Exercise*, *33*(7), 1157-1167.

Rozzi, S.L., Lephart, S.M., & Fu, F.H. (1999). Effects of muscular fatigue on knee joint laxity and neuromuscular characteristics of male and female athletes. *Journal of Athletic Training*, *34*(2), 106.

Rozzi, S.L., Lephart, S.M., Gear, W.S., & Fu, F.H. (1999). Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *The American Journal of Sports Medicine*, *27*(3), 312-319.

Skinner, H., Wyatt, M., Hodgdon, J., Conard, D., & Barrack, R. (1986). Effect of fatigue on joint position sense of the knee. *Journal of Orthopaedic Research*, *4*(1), 112-118.

Skinner, H., Wyatt, M., Stone, M., Hodgdon, J., & Barrack, R. (1986). Exercise-related knee joint laxity. *The American Journal of Sports Medicine*, *14*(1), 30-34.

Weltman, A. (1995). *The blood lactate response to exercise*. Champaign, IL: Human Kinetics.

Winter, D.A. (1990). *Biomechanics and motor control of human movement.* New York: John Wiley & Sons.

Wojtys, E.M., Wylie, B.B., & Huston, L.J. (1996). The effects of muscle fatigue on neuromuscular function and anterior tibial translation in healthy knees. *The American Journal of Sports Medicine*, *24*(5), 615-621. https://doi.org/10.1177/036354659602400509

Submitted: January 3, 2024
Accepted: January 10, 2024
Published Online First: December 10, 2024

Correspondence to:
Eric M. Mosier, Ph.D.
Exercise Science Laboratory, Kinesiology
Department, Washburn University
Petro Allied Health Center, Room 201F
SW Mulvane St. Topeka, KS 66621
Email: eric.mosier@washburn.edu

COMBINED EXERCISE TRAINING PROGRAMME LEADS TO DIFFERENT EFFECTS ON POWER, MUSCULAR ENDURANCE AND BALANCE OF INSTITUTIONALIZED PERSONS WITH INTELLECTUAL DISABILITIES

Marko Štrucelj, Ivan Horvat, and Tatjana Trošt Bobić

University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Original scientific paper

DOI 10.26582/k.56.2.7

Abstract:

People with intellectual disabilities have a reduced level of physical fitness. Institutionalization may be one of the important factors associated with their lower level of physical activity. Implementing a training intervention for institutionalized adults with intellectual disabilities requires an innovative and individually tailored approach that may differ from the approach for the general population. This study aims to determine the effects of a newly designed exercise training programme, consisting of neuromuscular exercises and outdoor walking training, on muscular endurance, power, and balance of institutionalized adults with intellectual disabilities. The participants were 90 institutionalized adults (43.9 ± 9.0 years), with mild to moderate intellectual disabilities, randomly assigned into a control (n=45) or an experimental group (n=45). The experimental group participated in the experimental training programme for 12 weeks (60 training sessions). In the experimental group**,** participants' muscular endurance (p=.01) and power (p=.04) were significantly improved without major changes in balance. The latter was probably due to a small amount of specific postural exercises in the applied combined exercise programme. Future research should focus on finding an appropriate volume of postural control exercises to stimulate balance improvement in this specific population.

Key words: *cognitive impairment, physical fitness, neuromuscular training, walking, postural control*

Introduction

The prevalence of sedentary behaviour in people with intellectual disability (ID) is significantly higher than in the general population (Cartwright, Reid, Hammersley, & Walley, 2017; Hsieh, Hilgenkamp, Murthy, Heller, & Rimmer, 2017; Kreinbucher-Bekerle, Ruf, Bartholomeyczik, Wieber, & Kiselev, 2023; Oviedo, Travier, & Guerra-Balic, 2017). Only a small percentage of adults with ID meet the World Health Organization's (WHO) recommendations for daily physical activity (PA), and even active individuals manage to achieve only levels of physical activity that are comparable to those of less active individuals in the general population (Hsieh, et al., 2017; Oviedo, et al., 2017). Lack of PA and a sedentary lifestyle negatively affect their physical fitness and overall health (Ferreira, et al., 2022; Hsieh, et al., 2017; Jacinto, et al., 2021; Oviedo, et al., 2017; Ptomey, et al., 2019). People with ID have a reduced level of cardiorespiratory fitness, muscle strength and endurance with the frequently accompanying balance disorder (Bahiraei, Oviedo, & Hosseini, 2023; Jacinto, et al., 2021; Ptomey, et al., 2019; Scifo, et al., 2019). As a result, they have a lower quality of life, a greater number of health problems, significantly increased living and health care costs and a shorter life expectancy compared to the general population (Jacinto, et al., 2021; Ptomey, et al., 2019; Scifo, et al., 2019; Simões, Santos, & Claes, 2015).

Individuals with ID are highly dependent on other people's help and need constant support in various aspects of everyday life (Bossink, van der Putten, Waninge, & Vlaskamp, 2017; Overwijk, Hilgenkamp, van der Schans, van der Putten, & Waninge, 2021; Reguera-García, Fernández-Baró, Diez-Vega, Varona-Echave, & Seco-Calvo, 2023). For those reasons, they are often homed in specialized rehabilitation centres or group homes, thus making institutionalization a dominant form of residential accommodation for adults with ID (Bossink, et al., 2017; Dixon-Ibarra, Driver, Vanderbom & Humphries, 2017; Overwijk, et al., 2021). In such conditions, their opportunities to engage in regular PA may be further reduced and limited. Additionally, within the centres, they can meet all their vital needs. In these circumstances, their motivation to be physically active gradually decreases. Institutionalization may be one of the important factors associated with a lower level of PA in people with ID (Bossink, et al., 2017; Dixon-Ibarra, et al., 2017). For these reasons, the process of planning and implementing a physical exercise intervention for institutionalized adults with ID requires an innovative and tailored approach that may differ from the approach for the general population (Oviedo, et al., 2017; Rodrigues, Jacinto, Figueiredo, Monteiro, & Forte, 2023). The potential effect of programmed physical exercise on the physical fitness of institutionalized persons with ID is an insufficiently explored area, and numerous physical exercise interventions for the people with ID used in daily practice are based on studies carried out with the general population (Pitchford, Dixon-Ibarra, & Hauck, 2018).

Specific exercise programmes may develop motor abilities and, by doing so, enhance physical fitness of people with ID (Obrusnikova, Firkin, Cavalier, & Suminski, 2022). Most previous research studies indicate the possibility of positive changes in muscular strength and endurance as well as in balance under the influence of physical exercise programmes (Jacinto, et al., 2021; Scifo, et al., 2019). However, the results are predominantly based on the application of isolated exercise programmes aimed at developing targeted motor abilities. Research shows that specific strength exercises for people with ID can contribute to their better daily living performance and prevention of muscle mass loss (Jacinto, et al., 2021; Maine, et al. 2020). Targeted physical exercise programmes may also improve muscle endurance (Tamin, Idris, Mansyur, & Soegondo, 2015) and balance (Lee, Lee, & Song, 2016). Only a few studies, with inconsistent results, investigated the possibility of obtaining similar effects by the application of more complex training programmes that combine several different types of exercises so they could have a more comprehensive effect on physical fitness covering health and skill- or performance-related physical fitness (Bouzas, Ayán, & Martínez-Lemos, 2019; Rodrigues, et al., 2023). More complex training programmes may even be more interesting and maybe more successful in motivating people with ID to engage in PA and stay active.

Newer research provides encouraging evidence about the possibility of a positive effect of combined physical exercise and walking programmes on improving health of people with ID (Lin, 2021). Walking is a widespread PA and is generally accepted as an appropriate activity for the initial activation of physically inactive individuals (Matthews, et al., 2016; Melville, et al., 2015). Regular walking has a wide range of health benefits for the individual; however, this type of intervention has rarely been used with institutionalized persons with ID (Matthews, et al., 2016; Melville, et al., 2015). People with ID walk at a lower intensity, less frequently and for a shorter duration compared to the general population (Elbers, de Oude, Kastanidis, Maes-Festen, & Oppewal, 2022; Matthews, et al., 2016; Melville, et al., 2015; Van Hanegem, Enkelaar, Smulders, & Weerdesteyn, 2014). For people with ID, walking is recommended as one of the most practical forms of exercise to achieve target levels of daily PA (Matthews, et al., 2016). The main advantages of walking, compared to the other aerobic forms of physical exercise available to people with ID, are that walking does not require any additional special skills or previous knowledge, it is usually completely free, and it can be practiced by previously extremely inactive individuals (Stancliffe, & Anderson, 2017).

Finally, due to the above-mentioned specificities of the institutionalized people with ID, it is reasonable to assume that an exercise programme for the institutionalized adults with ID should be appealing to initially motivate them to get involved and to ensure their regular attendance. It should also focus on simple, quickly understandable, but effective exercises. Additionally, it may be useful if the implementation of such a programme would be independent of specialized devices because not every Centre has the same living and working conditions. The aim of this study was to determine the effects of a newly designed exercise programme combining neuromuscular and walking exercises on the power, endurance, and balance of institutionalized adults with ID. The idea was to implement an exercise programme that combined a wide range of different neuromuscular tasks as well as outdoor walking training that people with ID may find interesting and feel motivated to regularly attend training sessions.

Materials and methods

Study design

The conducted research represents a randomized control trial investigating the effects of a newly designed exercise training programme that combines neuromuscular and walking exercises on the power, endurance, and balance of institutionalized adults with ID. The research was conducted during the period from April to July 2022. It encompassed the initial (1 week) and final (1 week) testing of participants' motor abilities, an intervention training period (12 weeks) and two adaptation weeks (one for the testing procedures and one for the training protocol). Specifically, considering that people with ID need more time to familiarise themselves with new tasks (Obrusnikova, et al., 2022), a period of one week was planned before the initial testing to demonstrate the testing procedures to all the participants and let them accustomed to the tasks. An appropriate schedule was planned, and each participant had the same opportunity to see and try the tasks under the supervision of specialized therapists. After the initial testing, participants were randomly allocated either to the experimental group (EG) or to the control group (CG). The participants of the CG continued with their usual daily activities and did not engage in any organized form of physical exercise until the end of the study. On the other hand, the participants in the EG had a one-week period to adapt to the training procedures. Professional therapists explained and demonstrated the tasks in detail, and the participants had the opportunity to practice them. After that, the official 12-week intervention training period began. The exercise programme was carried out five times a week. In it, 60-minute neuromuscular training sessions (performed on Mondays, Wednesdays and Fridays) alternated with a 30-minute outdoor walking programme (performed on Tuesdays and Thursdays). The weekend was free from any organized PA.

Sample

The research was conducted with a sample of 90 persons with ID (31 females and 59 males) chronologically aged from 21 to 55 years (43.9 ± 9.0). Participants were adults with a diagnosed intellectual disability who were permanent residents of the Rehabilitation Centre “Nada” (Karlovac, Croatia), a specialized home for housing persons with ID. Estimates of the total sample size needed for this study were made using G*Power (version 3.1.9.7) (Faul, Erdfelder, Lang, & Buchner, 2007). A power analysis showed that a sample of at least 54 participants was required to detect a medium effect size (ES) of 0.5 (α=.05, 1−β =.95), in agreement with some previous studies (Bouzas, et al., 2019; Jacinto, et al., 2021). Considering that it is a relatively long and complex research with a specific population for which it is difficult to assess their level of cooperation in advance, and due to the presence of fear of participants dropping out, the study was planned with a total of 90 participants. Inclusion criteria were the following: diagnosed mild or moderate ID, age between 20 and 55 years, at least 12 consecutive months, without interruption, of accommodation in the Centre, and the ability to understand and follow verbal instructions. Exclusion criteria encompassed the following: musculoskeletal and/or neurological deficits, inability to walk independently, visual and hearing impairment, and presence of acute cardiovascular and/or respiratory diseases. The research was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013) and approved by the Ethics Committee of the Faculty of Kinesiology of the University of Zagreb (Protocol Code 34; date of approval 8-10 December 2021). Consent was also obtained from the Rehabilitation Centre “Nada”.

Randomisation

To ensure a balance between the experimental and control group during the randomisation process, pairs of participants were formed according to the following criteria: age, gender, body mass index (BMI) and degree of ID. One member of the pair was assigned to the experimental (n = 45) and the other to the control group (n = 45) using the method of random selection with computer program R, v.3.5.1. At the beginning of the research, the differences between the groups according to the randomisation criteria were determined using the chi-square test for categorical variables (gender, BMI and degree of ID) and the Mann-Whitney U test for a continuous variable (age) .

Measures

Anthropometry

Body weight and body height were measured in accordance with the standardised measurement procedures and carried out in the morning, before breakfast (Hsu, et al., 2021). During the measurement, all participants wore lightweight clothing and were barefoot. Body height was measured with an anthropometer (Seca 220, Seca BmbH & Co., Hamburg, Germany), and the result was recorded in centimetres (cm) with an accuracy of 0.5 cm. Body mass was measured with a medical decimal scale with a floating weight (Seca 711, Seca BmbH & Co., Hamburg, Germany), and the result was recorded in kilograms (kg) with an accuracy of 0.1 kg. BMI was calculated as weight in kilograms divided by height in squared metres (kg/m^2).

Power

Power was assessed using the standing long jump test (Martínez-Aldao, Martínez-Lemos, Bouzas-Rico, & Ayán-Pérez, 2019). This test has been considered a reliable method for assessing lower-body muscle power in adults with ID (Martínez-Aldao, et al., 2019). The test was performed on a standard, non-slip, solid surface intended for the performance of the long jump test with marked starting position and distances in centimetres (0-300 cm). Participants stood with both feet over the edge of the starting line, crouched down and jumped as far as possible using a double-leg take-off and an arm swing. After each jump, the distance from the starting line to the part of the participant’s body that was closest to the starting line was recorded. The result was recorded in centimetres with an accuracy of 1 cm.

Muscular endurance

Abdominal and hip flexors' muscular endurance was tested using the 60-second sit-up test (Hsu, et al., 2021). This fitness testing protocol was chosen because it is easy to administer and it has been used often in clinical research to test the muscular endurance of adults with ID (Hsu, et al., 2021). The participants lay on their backs with their knees bent at 90° and arms crossed over the chest with palms on the opposite shoulders. The examiner fixed the participants' feet while the participants were raising their upper bodies as quickly as possible to a sitting position, touching their upper legs with their elbows, and then returning to the initial position. The examiner counted the correctly performed sit-ups for a period of 60 seconds.

Balance

Balance was measured using the Microgate Gyko device (Cigrovski, Franjko, Bon, Očić, & Božić, 2018). The device was positioned in the middle of a balance board, which was wobbling in the transverse plane (antero-posterior movement), on which the participant should stand as still as possible. Displacement of the board was measured with an accuracy of 1 mm. The standing surface of the balance board was 40 x 40 cm, and the maximal height between the floor and the standing surface was 12 cm. The balance board was constructed to allow movements exclusively in the anterior-posterior direction. Participants stood as still as possible with both their legs on the board in a semi-squat position with their eyes open and arms freely placed next to the body. Before the measurement, the participants (assisted by the examiner) completely calmed the balance board to carry out the calibration of the measuring device for each new measurement. Upon the sound signal produced by the Gyko device, the participants tried to stand as still as possible on the balance board for 30 seconds. The variables of interest used in this research were the total antero-posterior movement (cm) and the total frequency of movement (Hz) of the balance board.

Intervention

A newly designed exercise training programme for institutionalized adults with ID, which combines neuromuscular and walking exercises, was implemented five times per week. Neuromuscular training (three times a week for 60 minutes) alternated with outdoor walking training (twice a week for 30 minutes). During the weekend, the subjects were not engaged in any organized training. During the intervention period, a total of 60 training sessions were conducted (36 neuromuscular training sessions and 24 outdoor walking). Training attendance was monitored and a minimum required attendance of 80 % was determined in order to consider the participation in the study valid for further analysis. The exercise programme was designed by a group of specialists with twenty years of work experience in health care, kinesiology, physiotherapy, and psychology, as well as with many years of experience working with people with ID. The current guidelines for physical exercise for people with ID from the world's most influential institutions, such as WHO and The American College of Sports Medicine (ACSM) (American College of Sports Medicine, 2018; WHO, 2020), were taken into consideration. The weekly combination of separated neuromuscular and walking training sessions brings something new, more complex and challenging to people with ID compared to usual programmes that involved the implementation of very simple movement patterns. The idea was that a wide range of training tasks would be more interesting to people with ID, leading to their better compliance and, finally, to their better motor adaptation. The intervention was performed without the use of specific trainers because the goal was to check the effectiveness of an interesting but widely applicable training without the need for specialized equipment.

Neuromuscular training was conducted in smaller subgroups of 15 participants each. The participants performed a set of exercises adapted to improve muscular strength, power, endurance, and balance. Each training session was divided into four parts: the introductory part of the training (10 minutes), main part A (30 minutes), main part B (10 minutes), and the final part of the training (10 minutes).

During the introductory part of the neuromuscular training session, general whole-body exercises were performed. The goal of these exercises was to warm up the participants for the main part of the training and to prepare their body for increased physiological efforts and activities. Main part A of the training was divided into two units: muscular strength, power, and endurance exercises (20 minutes), and balance exercises (10 minutes). A combination of eight endurance, power and strength exercises involving large muscle groups was performed as well as five different balance exercises. Main part B of the training was planned for sports games and four different sports games were used in this programme. In the final part of the training session, stretching exercises for large muscle groups were carried out. During the entire exercise programme, participants performed the same five stretching exercises. Each exercise was performed two times for 30 seconds, and the rest between each repetition lasted 30 seconds as well. During the 12-week training period, load progression was applied at two time points. Firstly, after four weeks of exercise, and secondly, after the next four weeks, i.e., after a total of eight weeks of exercise. All load progressions were predefined and were carried out by increasing the intensity, volume and demands of the exercises in accordance with current recommendations for physical exercise for people with ID (American College of Sports Medicine, 2018; WHO, 2020). For endurance, power, and strength, the number of repetitions were progressively increased, while load progression for the balance tasks was achieved by replacing the existing exercises with more demanding ones. In addition, before each load progression, a subjective assessment of the perceived exertion from 0 (not tired at all) to 10 (very, very tired) was done using the Children's OMNI Scale of Perceived Exertion, which was previously demonstrated valid for subjective assessment of training load of adult people with ID (Stanish & Aucoin, 2007). The exercises as well as the training load are presented in Tables 1 and 2.

Table 1. Neuromuscular training – muscular strength, power and endurance exercises

Exercise		*Sets x reps*			
		Training week 1-4	*Training week 5-8*	*Training week 9-12*	*Rest*
Muscular strength, power and endurance exercises					
1.	Flexion of forearms with 1.5 kg weights	3 x 10	3 x 12	3 x 14	1-2 min
2.	Lifting 1.5 kg weights anteriorly and laterally	3 x 10	3 x 12	3 x 14	1-2 min
3.	Lying in a supine position, sit-ups with the hands placed on the chest	3 x 10	3 x 12	3 x 14	1-2 min
4.	Lying in a supine position with support on the forearms. Raising the legs to the chest with knee flexion	3 x 10	3 x 12	3 x 14	1-2 min
5.	Lying in a pronated position, the hands above the head, dynamic trunk extensions	3 x 10	3 x 12	3 x 14	1-2 min
6.	Lying in a pronated position, the hands next to the body, dynamic trunk extensions	3 x 10	3 x 12	3 x 14	1-2 min
7.	Parallel squat	3 x 10	3 x 12	3 x 14	1-2 min
8.	Alternation of left and right lunges	3 x 10	3 x 12	3 x 14	1-2 min

Table 2. Neuromuscular training – balance exercises

Training week	*Exercise*		*Sets x Duration*	*Rest*
1-4	1.	Parallel stance, the arms extended above the head, alternating trunk flexion (anteriorly) and extension (posteriorly)	2 x 30 sec.	1 min
	2.	Parallel stance, the hands next to the body—turning in place around one's own vertical axis	2 x 30 sec.	1 min
	3.	Semi-tandem stance with the eyes closed—the hands above the head	2 x 30 sec.	1 min
	4.	Tandem stance with the eyes closed—the hands above the head	2 x 30 sec.	1 min
	5.	Standing on one leg, alternating the standing leg, lateral arms rise	2 x 30 sec.	1 min
5-8	1.	Walking straight, placing each foot in front of the other (15 m)	2 x 30 sec.	1 min
	2.	Walking sideways, placing each foot parallel to the other (15 m)	2 x 30 sec.	1 min
	3.	Walking straight backwards, placing each foot behind the other (15 m)	2 x 30 sec.	1 min
	4.	Tandem stance, holding the ball with both hands anteriorly at shoulder height—alternating trunk rotations to the right and left	2 x 30 sec.	1 min
	5.	Standing alternately on the right and left leg, holding the ball with both hands anteriorly at shoulder height—alternating rotation of the trunk to the right and left	2 x 30 sec.	1 min
9-12	1.	Walking straight, placing each foot in front of the other (15 m) with sudden stopping and eyes closing at the sound signal	2 x 30 sec.	1 min
	2.	Walking sideways, placing each foot parallel to the other (15 m) with sudden stopping and eyes closing at the sound signal	2 x 30 sec.	1 min
	3.	Walking straight backwards, placing each foot behind the other (15 m) with sudden stopping and eyes closing at the sound signal	2 x 30 sec.	1 min
	4.	Tandem stance, holding the ball with both hands anteriorly at shoulder height—alternating trunk rotations to the right and left with sudden stopping and eyes closing at the sound signal	2 x 30 sec.	1 min
	5.	Standing alternately on the right and left leg, holding the ball with both hands anteriorly at shoulder height—alternating rotation of the trunk to the right and left side with sudden stopping and eyes closing at the sound signal	2 x 30 sec.	1 min

The outdoor walking training was conducted in small homogeneous subgroups of a maximum nine participants having similar motor abilities. Walking training took place in the courtyard of the Rehabilitation Centre over a specially marked polygon with a rectangular shape and a total length of 100 m (dimensions: 40 m x 10 m). The training load progression was carried out following the recent ACSM recommendations for people with ID, which suggested a gradual increase from light to moderate-intensity activities (American College of Sports Medicine, 2018). In accordance with this, for the first four weeks, the participants walked at a speed of up to 4.8 km/h, which corresponded to an activity of light intensity. For the next four weeks, the participants walked at a speed of 4.8-6.4 km/h, while in the last four weeks, walking speed was 6.4-7.2 km/h. Walking speed applied in the period of 5^{th} to 12^{th} week of the programme (4.8-7.2 km/h) corresponded to moderate intensity of physical activity (American College of Sports Medicine, 2018). During the outdoor walking training, the participants were continuously informed about the remaining time and at the same time, they received instructions if their walking speed needed to be corrected.

Main analyses

During the research, two participants from the EG did not meet the criterion of regular attendance (attendance less than 80%), and one participant from the CG fell ill and was not present at the final testing. For this reason, statistical analysis was performed on the total sample of 87 participants. For power assessment, each participant performed the test three times, and the best result was used for data analysis. The balance task was also performed three times, but the arithmetic mean of three repetitions was used in the statistical analysis. The endurance test was performed only once.

In data processing, standard statistical methods were used to determine descriptive parameters: arithmetic mean (M) and standard deviation (SD). The normality of the distribution was analysed using the Shapiro-Wilk test. The test showed a normal distribution only for the variable measuring power in both groups. The data for all the other variables (measuring muscular endurance and balance in both groups) were not normally distributed. For further analysis, parametric statistics was used on normally distributed variables, while non-parametric tests were used for variables with a non-normal distribution.

To assess the statistical significance of changes between the initial and final testing within the tested groups, the Student's t-test for dependent samples was performed on the normally distributed variables, while the Wilcoxon Signed-Rank test was used for the ones with a non-normal distribution. To check for the practical significance of the achieved results, the effects size was calculated using the Cohen's index (normal distribution) or the r parameter (non-normal distribution).

According to Muhammad (2023), when variables are non-normally distributed, it is not possible to perform a repeated-measure ANOVA. Since, in our case, not all the variables were normally distributed, to test the between-group statistical significance of change between the initial and final measurement new variables were formed (derived by calculating the differences between the results of the final and initial testing, that is "final - initial"). These new (difference) variables were also tested for normality of distribution by means of the Shapiro-Wilk test. The variables measuring power and balance with total frequency of movement of the balance board had a normal data distribution, while the one measuring muscular endurance and balance with antero-posterior movement of the balance board had not. To check for between-group differences in normally distributed data, the Student t-test for independent samples was performed, while in case of non-normal distribution, the Mann-Whitney U test was used.

Statistical data processing was performed using the Statistica for Windows 14.0 software package (StatSoft Inc., Tulsa, OK). Statistical significance was set at $p<.05$.

Results

At the beginning of the study, there were no significant differences between the two groups in age (p=.18), gender (p=.15), BMI (p=.24) and degree of ID (p=.16). Also, there were no significant differences in the tested motor abilities between the two groups (power: p=.89; muscular endurance: p=.55; balance [antero-posterior movement]: p=.42; balance [frequency of movement]: p=.67).

Table 3 points out descriptive statistical parameters and statistical significance between the initial and final testing for the CG and EG separately. In the EG, although a positive trend of change was observed in all the variables, statistical significance was obtained only for power ($p<.01$), with a medium effect size. No statistically significant changes were detected between the initial and final measurements in the CG.

As stated before, since not all the variables had normally distributed data, in order to check for the between-group differences in changes from the initial to final measurement, a new variable consisting of the difference between the final and initial testing (final – initial) for each measured motor ability in each group was calculated. Table 4 shows descriptive statistical parameters of these new variables. It also shows the between-

Table 3. Descriptive statistics for the initial and final testing as well as the results of the Student t-test for dependent samples and Wilcoxon sign test for each variable for both groups

Variables	*Control group*				*Experimental group*			
	Initial testing	*Final testing*	*p*	*ES*	*Initial testing*	*Final testing*	*p*	*ES*
	M ± SD	*M ± SD*			*M ± SD*	*M ± SD*		
PowerSt	80.07 ± 47.69	78.52 ± 48.99	0.94	-0.03	81.49 ± 44.94	84.23 ± 48.59	0.11	0.11
Endurance^{W}	12.14 ± 10.64	13.7 ± 10.89	0.12	0.12	13.42 ± 10.67	19.21 ± 9.81	<0.01*	0.43
Balance_ movement^{W}	67.12 ± 34.52	68.17 ± 36.55	0.55	0.01	61.09 ± 29.58	59.87 ± 23.84	0.63	-0.04
Balance_ freequency^{W}	0.54 ± 0.22	0.52 ± 0.22	0.35	-0.04	0.52 ± 0.26	0.46 ± 0.23	0.07	-0.17

Note. M-arithmetic mean; SD-standard deviation; p-significance indicator; ES-effect size; Balance_movement-measure of balance indicating the total antero-posterior movement of the balance board; Balance_freequency-measure of balance indicating the total frequency of movement of the balance board; St-Student t-test for dependent samples, used to process normally distributed data; W-Wilcoxon test, used to process non-normally distributed data; *-significant interaction (p<.05)

Table 4. Descriptive statistics of the newly derived difference variables, and between-group differences assessed by means of the Student t-test for independent samples and Mann-Whitney U test

Variables	*Control group*	*Experimental group*	*p*
	M ± SD	*M ± SD*	
Power_*diff*St	-1.55 ± 6.55	2.74 ± 14.65	0.04*
Endurance_*diff*^{MW}	1.57 ± 7.25	5.79 ± 8.03	0.01*
Balance_movement_*diff*^{MW}	1.05 ± 25.77	-1.22 ± 24.35	0.53
Balance_frequency_*diff*St	-0.01 ± 0.16	-0.06 ± 0.19	0.13

Note. M-arithmetic mean; SD-standard deviation; p-significance indicator; Balance_movement-measure of balance indicating the total antero-posterior movement of the balance board; Balance_freequency-measure of balance indicating the total frequency of movement of the balance board; St-Student t-test for independent samples, used to process normally distributed data; MW-Mann-Whitney U test, used to process non-normally distributed data; diff-indicating that the variable has been calculated by subtracting the result achieved in the initial testing from the result achieved in the final testing; *-significant interaction (p<.05)

group differences in these variables. Statistically significant between-group differences were found for power (p=.04) and muscular endurance (p=.01).

Discussion and conclusions

The aim of this study was to determine the effects of a newly designed exercise training programme, combining neuromuscular and walking exercises, on the power, endurance and balance of institutionalized adults with ID. The obtained results showed that the newly designed exercise training programme led to a significant improvement in power and muscular endurance without statistically significant changes in balance. This indicates an improvement in health-related (muscular endurance) as well as performance-related physical fitness (power) indicators. It has been well-documented that people with ID have suboptimal levels of power, muscular endurance, and balance, compared to persons without ID (Bahiraei, Oviedo, & Hosseini, 2023; Elbers, et al., 2022; Graham, & Reid, 2000; Jacinto, et al., 2021). This is especially true for institutionalized people with ID, who tend to spend a large portion of the day in sedentary behaviours (Bossink, et al., 2017; Dixon-Ibarra, et al., 2017). The here documented level of muscular endurance is still below the expected value for the general population (Yanardag, Arikan, Yilmaz, & Konukman, 2013); however, the fact that the institutionalized adults with ID had significantly improved it may have an important implication in their everyday life. Muscular power may be crucial to promote mobility, cardiovascular capacity, and performance of daily living like recreational and vocational activities in adults with ID (Obrusnikova, et al., 2022). In previous research, specific training programmes were used to enhance muscular properties (Jacinto, et al., 2021), rather than a more complex one like in our study. A few studies included a combined type of training, but most of them did not plan a comprehensive programme that combined strength exercises, balance exercises, and daily activities. Calders et al. (2011) planned a 20-week specific aerobic training with two training sessions per week and compared it to a combination of aerobic and strength exercises performed in a gym. Their results show a better improvement of muscle fatigue resistance measured by a sustained handgrip contraction in people with ID, mean age 42 ± 9.2 years, after the combined training. The training period used by Calders et al. (2011) had in total fewer training sessions than the one carried out in our study; however, it was a specific one and aimed only at muscular strength and endurance improvement, without additional exercise for postural control or outdoor walking. Stanish and Temple (2012) studied the effect of a 15-week aerobic training, weight training and stretching, performed twice a week, on muscular fitness of adolescents with ID. The programme led to a significant improvement in muscular endurance. Although this research was carried out with adolescents with ID, it might be interesting to point out that they exercised peer support in order to increase their training attendance. Regardless of that, the authors stated that weight training exercises were completed less consistently, which might indicate a lower motivation for this kind of exercise in people with ID. Since muscular endurance may help people with ID to better perform daily activities and improve their physical fitness and overall health, it is important to find new ways of training to encourage them to get involved as much as possible and develop this health-important muscular feature. Since the overall attendance in our study was very high (only two participants failed to attend 80% of the training sessions), the here presented complex training may be one way to deal with this challenge.

The significant improvement in the muscular power of the institutionalized adults with ID registered in our study is most probably due to the neuromuscular component of the implemented training programme. The comparison with similar previous studies is difficult because researchers have mostly focused on targeted strength and power training. Recent systematic reviews reported the possibility of obtaining positive effects on power using a combined exercise intervention in people with mild to moderate ID (Bouzas, et al., 2019; Farías-Valenzuela, et al., 2022; Jacinto, et al., 2021). However, in most previous studies resistance training was used (combining exercises to develop muscular strength, power and endurance) to improve power. The authors achieved similar results using resistance training interventions lasting from nine to 12 weeks with one to three training sessions per week (Bouzas, et al., 2019; Jacinto, et al., 2021). Here, a 12-week complex training programme was carried out with three neuromuscular sessions and two outdoor walking sessions weekly. Another important difference between our exercise programme and the ones usually used in previous studies is that we did not use a specialized gym or equipment for resistance training like chest press, leg extension, abdominal muscle trainer and others. The exercises were body-weight exercises with the addition of simple weights that are available in any sports stores. The focus was on the study of the effectiveness of the newly designed exercise programme, which can later be easily implemented in any rehabilitation centre, regardless of the equipment at their facilities. According to the obtained data, the programme could lead to a significant improvement in the muscular power of institutionalized adults with ID. Great power means a large amount of work or energy developed in a short time. This may help adults with ID to climb stairs and move faster in daily activities, thus enhancing their physical functioning. The importance of enhancing power in such a specific population like institutionalized adults with ID is even greater when taking into consideration that comparative studies have found muscle power is more strongly associated with physical function than muscle strength and has been independently associated with mortality, even to a greater extent than muscle strength (Alcazar, Guadalupe-Grau, García-García, Ara, & Alegre, 2018). Thus, the here obtained enhancement in muscle power may preserve the health and physical independence of adults with ID.

The ability to quickly exert maximum force, which stands in the background of power, is highly correlated with the ability of the neuromuscular system to quickly and timely correct the body position in space (Lauber, Gollhofer, & Taube, 2021). Muscle contraction speed is important for power as well as for balance tasks performance. In line with that, one would expect that the established improvement in power would be accompanied by a significant improvement in balance. However, although there was a positive trend of progress in balance, statistical significance was not reached. Oviedo, Guerra-Balic, Baynard, and Javierre (2014) managed to improve balance in adults with ID by implementing a 14-week exercise programme consisting of aerobic, strength and balance exercises performed three times a week. More recently, the possibility of enhancing balance in adults with ID aged 18 to 50 years with a 4-month multicomponent balance-specific exercise programme performed twice a week has also been proven; however, participants were younger and belonged to a population defined as "athletes that did not match the WHO recommendations for daily activity" (Kovačič, Kovačič, Ovsenik, & Zurc, 2020). Although participants in previous studies were younger (Kovačič, et al., 2020) or trained longer (Oviedo, et al., 2014), it is possible that the exercise intervention in our study was not sufficiently focused on improving balance in institutionalized people with ID. If improving balance is the aim, then more postural-oriented tasks should be implemented in the training programme. This issue is extremely important since people with ID present postural control deficits that can be attributed to several sources and that may be a cause of support needed in different aspects of daily life for better individual functioning (Bahiraei, et al., 2019; Reguera-García, et al., 2023).

There is a limited number of studies confirming positive changes in the deficient motor abilities of institutionalized adults with mild to moderate ID following a combined exercise intervention. Lower levels of motor abilities and connected health issues are highly prevalent in this population (Ferreira, et al., 2022; Hsieh, et al., 2017; Oviedo, et al., 2017; Vancampfort, et al., 2022). Our study findings showed that a 12-week complex training protocol, consisting of neuromuscular exercises and outdoor walking, may improve muscular endurance and power in institutionalized adults with ID but may be too general to develop balance. The exercise intervention used in this randomised control trial was designed to be easily applicable and incorporable into the daily routine of institutionalized people with ID. It was also planned to make it interesting and motivating for the participants to ensure regular attendance. This study design has several limitations which need to be discussed. Generalizing the obtained results to all individuals with ID should be done with caution, since the study was performed with the institutionalized persons with mild to moderate ID. Furthermore, the here used training programme is not adapted to individuals with profound ID. Also, the lack of blinding of the examiner during the measurement may introduce measurement bias. The duration of our exercise programme was 12 weeks, and no follow-up measurements were done to determine whether the achieved changes had been maintained.

In summary, the results of the conducted research indicate that a 12-week complex training, including strength, endurance, power, and balance exercises as well as regular outdoor walking, may develop performance and health-related physical fitness of institutionalized adults with ID through muscular endurance and power enhancement, but it was not specific enough to enhance balance in this population. Considering the less developed motor abilities of people with ID and the lower quality of their overall health, the need to include people with ID in regular physical exercise is constantly emphasized. Recently, the importance of finding a way to motivate this population to exercise regularly has also been expressed. The programme applied here was planned as a simple and feasible training that can be performed in almost any working setting. It also included a considerable variability of exercises to be more interesting to people with ID and thus hopefully motivate them to attend it regularly. High attendance was achieved, and muscular endurance and power were developed. However, it seems it did not focus enough on balance improvement in this specific population. Future research should focus on exploring the ideal balance between the attractiveness of tasks and their effectiveness in developing targeted motor skills and abilities in people with ID.

References

Alcazar, J., Guadalupe-Grau, A., García-García, F.J., Ara, I., & Alegre, L.M. (2018). Skeletal muscle power measurement in older people: A systematic review of testing protocols and adverse events. *The Journals of Gerontology: Series A, Biological Sciences and Medical Sciences*, *73*(7), 914-924. https://doi.org/10.1093/gerona/glx216

American College of Sports Medicine. (2018). *ACSM's guidelines for exercise testing and prescription* (D. Riebe, J.K. Ehrman, G. Liguori & M. Magal, Eds.; 10th edition). Wolters Kluwer.

Bahiraei, S., Daneshmandi, H., Norasteh, A.A., & Yahya, S. (2019). Balance stability in intellectual disability: Introductory evidence for the Balance Evaluation Systems Test (BESTest). *Life Span and Disability*, *22*(1), 7-28.

Bahiraei, S., Oviedo, G.R., & Hosseini, E. (2023). The effects of postural training on gait kinematics in individuals with intellectual and developmental disabilities. *Symmetry*, *15*(5), 1062. https://doi.org/10.3390/sym15051062

Bossink, L.W., van der Putten, A.A., Waninge, A., & Vlaskamp, C. (2017). A power-assisted exercise intervention in people with profound intellectual and multiple disabilities living in a residential facility: A pilot randomised controlled trial. *Clinical Rehabilitation*, *31*(9), 1168-1178. https://doi.org/10.1177/0269215516687347

Bouzas, S., Ayán, C., & Martínez-Lemos, R.I. (2019). Effects of exercise on the physical fitness level of adults with intellectual disability: A systematic review. *Disability and Rehabilitation*, *41*(26), 3118-3140. https://doi.org/10.1080/09638288.2018.1491646

Calders, P., Elmahgoub, S., de Mettelinge, T.R., Vandenbroeck, C., Dewandele, I., Rombaut, L., Vandevelde, A., & Cambier, D. (2011). Effect of combined exercise training on physical and metabolic fitness in adults with intellectual disability: A controlled trial. *Clinical Rehabilitation*, *25*(12), 1097-1108. https://doi.org/10.1177/0269215511407221

Cartwright, L., Reid, M., Hammersley, R., & Walley, R.M. (2017). Barriers to increasing the physical activity of people with intellectual disabilities. *British Journal of Learning Disabilities*, *45*(1), 47-55. https://doi.org/10.1111/bld.12175

Cigrovski, V., Franjko, I., Bon, I., Očić, M., & Božić, I. (2018). Recreational level alpine skiing and balance—A causative relationship? *Acta Kinesiologica*, *12*(2), 67-71.

Dixon-Ibarra, A., Driver, S., Vanderbom, K., & Humphries, K. (2017). Understanding physical activity in the group home setting: A qualitative inquiry. *Disability and Rehabilitation*, *39*(7), 653-662. https://doi.org/10.3109/09638288.2016.1160294

Elbers, R.G., de Oude, K.I., Kastanidis, T., Maes-Festen, D.A.M., & Oppewal, A. (2022). The effect of progressive resistance exercise training on cardiovascular risk factors in people with intellectual disabilities: A study protocol. *International Journal of Environmental Research and Public Health*, *19*(24), 16438. https://doi.org/10.3390/ijerph192416438

Farías-Valenzuela, C., Ferrero-Hernández, P., Ferrari, G., Cofre-Bolados, C., Espoz-Lazo, S., Álvarez-Arangua, S., Marques, A., & Valdivia-Moral, P. (2022). Effects of multicomponent physical exercise programs on physical fitness in people with intellectual disabilities: A systematic review. *Sustainability*, *14*(24), 16728. https://doi.org/10.3390/su142416728

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191. https://doi.org/10.3758/BF03193146

Ferreira, J.P., Matos, R., Campos, M.J., Monteiro, D., Antunes, R., & Jacinto, M. (2022). Effects of physical exercise program in adults with intellectual and developmental disabilities—A study protocol. *Journal of Clinical Medicine*, *11*(24), 7485. https://doi.org/10.3390/jcm11247485

Graham, A., & Reid, G. (2000). Physical fitness of adults with an intellectual disability: A 13-year follow-up study. *Research Quarterly for Exercise and Sport*, *71*(2), 152-161. https://doi.org/10.1080/02701367.2000.10608893

Hsieh, K., Hilgenkamp, T.I.M., Murthy, S., Heller, T., & Rimmer, J. (2017). Low levels of physical activity and sedentary behavior in adults with intellectual disabilities. *International Journal of Environmental Research and Public Health*, *14*(12), 1503. https://doi.org/10.3390/ijerph14121503

Hsu, P.-J., Chou, H.-S., Pan, Y.-H., Ju, Y.-Y., Tsai, C.-L., & Pan, C.-Y. (2021). Sedentary time, physical activity levels and physical fitness in adults with intellectual disabilities. *International Journal of Environmental Research and Public Health*, *18*(9), 5033. https://doi.org/10.3390/ijerph18095033

Jacinto, M., Oliveira, R., Brito, J.P., Martins, A.D., Matos, R., & Ferreira, J.P. (2021). Prescription and effects of strength training in individuals with intellectual disability—A systematic review. *Sports*, *9*(9), 125. https://doi.org/10.3390/sports9090125

Kovačič, T., Kovačič, M., Ovsenik, R., & Zurc, J. (2020). The impact of multicomponent programmes on balance and fall reduction in adults with intellectual disabilities: A randomised trial. *Journal of Intellectual Disability Research*, *64*(5), 381-394. https://doi.org/10.1111/jir.12727

Kreinbucher-Bekerle, C., Ruf, W., Bartholomeyczik, A., Wieber, F., & Kiselev, N. (2023). Recommending physical activity for people with intellectual disabilities: The relevance of public health guidelines, physical activity behaviour and type of contact. *International Journal of Environmental Research and Public Health*, *20*(8), 5544. https://doi.org/10.3390/ijerph20085544

Lauber, B., Gollhofer, A., & Taube, W. (2021). What to train first: balance or explosive strength? Impact on performance and intracortical inhibition. *Scandinavian Journal of Medicine and Science in Sports*, *31*(6), 1301-1312. https://doi.org/10.1111/sms.13939

Lee, K., Lee, M., & Song, C. (2016). Balance training improves postural balance, gait, and functional strength in adolescents with intellectual disabilities: Single-blinded, randomized clinical trial. *Disability and Health Journal*, *9*(3), 416-422. https://doi.org/10.1016/j.dhjo.2016.01.010

Lin, S.-Y. (2021). Effects of exercise interventions on frailty in pre-maturely aging adults with intellectual disabilities—A preliminary study. *Disability and Health Journal*, *14*(4), 101105. https://doi.org/10.1016/j.dhjo.2021.101105

Maine, A., Brown, M.J., Ski, C.F., Thompson, D.R., Marsh, L., & O'Leary, L. (2020). Recruitment settings, delivery contexts, intervention techniques and outcomes of health promotion programmes for young adults with intellectual and developmental disabilities: A systematic review. *Research in Developmental Disabilities*, *99*, 103592. https://doi.org/10.1016/j.ridd.2020.103592

Martínez-Aldao, D., Martínez-Lemos, I., Bouzas-Rico, S., & Ayán-Pérez, C. (2019). Feasibility of a dance and exercise with music programme on adults with intellectual disability. *Journal of Intellectual Disability Research*, *63*(6), 519-527. https://doi.org/10.1111/jir.12585

Matthews, L., Mitchell, F., Stalker, K., McConnachie, A., Murray, H., Melling, C., Mutrie, N., & Melville, C. (2016). Process evaluation of the Walk Well study: A cluster-randomised controlled trial of a community based walking programme for adults with intellectual disabilities. *BMC Public Health*, *16*, 527. https://doi.org/10.1186/s12889-016-3179-6

Melville, C.A., Mitchell, F., Stalker, K., Matthews, L., McConnachie, A., Murray, H.M., Melling, C., & Mutrie, N. (2015). Effectiveness of a walking programme to support adults with intellectual disabilities to increase physical activity: Walk Well cluster-randomised controlled trial. *International Journal of Behavioral Nutrition and Physical Activity*, *12*(125), 1-11. https://doi.org/10.1186/s12966-015-0290-5

Muhammad, L.N. (2023). Guidelines for repeated measures statistical analysis approaches with basic science research considerations. *Journal of Clinical Investigation*, *133*(11), e171058. https://doi.org/10.1172/JCI171058

Obrusnikova, I., Firkin, C.J., Cavalier, A.R., & Suminski, R.R. (2022). Effects of resistance training interventions on muscular strength in adults with intellectual disability: A systematic review and meta-analysis. *Disability and Rehabilitation*, *44*(17), 4549-4562. https://doi.org/10.1080/09638288.2021.1910738

Overwijk, A., Hilgenkamp, T.I.M., van der Schans, C.P., van der Putten, A.A.J., & Waninge, A. (2021). Needs of direct support professionals to support people with intellectual disabilities in leading a healthy lifestyle. *Journal of Policy and Practice in Intellectual Disabilities*, *18*(4), 263-272. https://doi.org/10.1111/jppi.12383

Oviedo, G.R., Guerra-Balic, M., Baynard, T., & Javierre, C. (2014). Effects of aerobic, resistance and balance training in adults with intellectual disabilities. *Research in Developmental Disabilities*, *35*(11), 2624-2634. https://doi.org/10.1016/j.ridd.2014.06.025

Oviedo, G.R., Travier, N., & Guerra-Balic, M. (2017). Sedentary and physical activity patterns in adults with intellectual disability. *International Journal of Environmental Research and Public Health*, *14*(9), 1027. https://doi.org/10.3390/ijerph14091027

Pitchford, E.A., Dixon-Ibarra, A., & Hauck, J.L. (2018). Physical activity research in intellectual disability: a scoping review using the behavioral epidemiological framework. *American Journal on Intellectual and Developmental Disabilities*, *123*(2), 140-163. https://doi.org/10.1352/1944-7558-123.2.140

Ptomey, L.T., Washburn, R.A., Lee, J., Greene, J.L., Szabo-Reed, A.N., Sherman, J.R., Danon, J.C., Osborne, L.N., Little, T.D., & Donnelly, J.E. (2019). Individual and family-based approaches to increase physical activity in adolescents with intellectual and developmental disabilities: Rationale and design for an 18 month randomized trial. *Contemporary Clinical Trials*, *84*, 105817. https://doi.org/10.1016/j.cct.2019.105817

Reguera-García, M.M., Fernández-Baró, E., Diez-Vega, I., Varona-Echave, I., & Seco-Calvo, J. (2023). Explanatory capacity of postural control and physical fitness in cognitive impairment and support needs among individuals with intellectual disabilities—A cross-sectional pilot study. *Brain Sciences*, *13*(8), 1213. https://doi.org/10.3390/brainsci13081213

Rodrigues, F., Jacinto, M., Figueiredo, N., Monteiro, A.M., & Forte, P. (2023). Effects of a 24-week low-cost multicomponent exercise program on health-related functional fitness in the community-dwelling aged and older adults. *Medicina*, *59*(2), 371. https://doi.org/10.3390/medicina59020371

Scifo, L., Borrego, C.C., Monteiro, D., Matosic, D., Feka, K., Bianco, A., & Alesi, M. (2019). Sport Intervention Programs (SIPs) to improve health and social inclusion in people with intellectual disabilities: A systematic review. *Journal of Functional Morphology and Kinesiology*, *4*(3), 57. https://doi.org/10.3390/jfmk4030057

Simões, C., Santos, S., & Claes, C. (2015). Quality of life assessment in intellectual disabilities: The Escala Pessoal de Resultados versus the World Health Quality of Life-BREF. *Research in Developmental Disabilities*, *37*, 171-181. https://doi.org/10.1016/j.ridd.2014.11.010

Stancliffe, R.J., & Anderson, L.L. (2017). Factors associated with meeting physical activity guidelines by adults with intellectual and developmental disabilities. *Research in Developmental Disabilities*, *62*, 1-14. https://doi.org/10.1016/j.ridd.2017.01.009

Stanish, H.I., & Aucoin, M. (2007). Usefulness of a Perceived Exertion Scale for monitoring exercise intensity in adults with intellectual disabilities. *Education and Training in Developmental Disabilities*, *42*(2), 230-239.

Stanish, H.I., & Temple, V.A. (2012). Efficacy of a peer-guided exercise programme for adolescents with intellectual disability. *Journal of Applied Research in Intellectual Disabilities*, *25*(4), 319-328. https://doi.org/10.1111/j.1468-3148.2011.00668.x

Tamin, T.Z., Idris, F.H., Mansyur, M., & Soegondo, S. (2015). Model and effectiveness of endurance exercise to increase physical fitness in intellectual disability subjects with obesity: A randomized controlled trial. *Acta Medica Indonesiana*, *47*(2), 127-135.

Van Hanegem, E., Enkelaar, L., Smulders, E., & Weerdesteyn, V. (2014). Obstacle course training can improve mobility and prevent falls in people with intellectual disabilities. *Journal of Intellectual Disability Research*, *58*(5), 485-492. https://doi.org/10.1111/jir.12045

Vancampfort, D., Van Damme, T., Firth, J., Stubbs, B., Schuch, F., Suetani, S., Arkesteyn, A., & Van Biesen, D. (2022). Physical activity correlates in children and adolescents, adults, and older adults with an intellectual disability: A systematic review. *Disability and Rehabilitation*, *44*(16), 4189-4200. https://doi.org/10.1080/09638288.2021.1909665

WHO—World Health Organization. (2020). *WHO guidelines on physical activity and sedentary behaviour*. Geneva: World Health Organization.

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, 310(20), 2191-2194. https://doi.org/10.1001/jama.2013.281053

Yanardag, M., Arikan, H., Yilmaz, I., & Konukman, F. (2013). Physical fitness levels of young adults with and without intellectual disability. *Kinesiology*, *45*(2), 223-240.

Submitted: May 20, 2024
Accepted: June 3, 2024
Published Online First: December 10, 2024

Correspondence to:
Tatjana Trošt Bobić, Ph.D.
Department of General and Applied Kinesiology
University of Zagreb, Faculty of Kinesiology,
Horvaćanski zavoj 15, 10000 Zagreb, Croatia
E-mail: tatjana.trost.bobic@kif.unizg.hr

ANALYSIS OF WEEKLY INTERNAL AND EXTERNAL LOAD FLUCTUATION IN PROFESSIONAL BASKETBALL

Roberto Molina[1], Daniel Lapresa[1], Javier Arana[1], Hugo Salazar[2], Ildefonso Álvarez-Marín[3], and Luka Svilar[4]

[1]*Department of Educational Sciences, University of La Rioja, Logroño, Spain*
[2]*Sports Performance Department, Saski Baskonia, Vitoria-Gasteiz, Spain*
[3]*Faculty of Humanities and Social Sciences. University Isabel I, Spain*
[4]*Faculty of Physical Activity and Sport Sciences, University of Basque Country, Spain*

Original scientific paper
DOI 10.26582/k.56.2.8

Abstract:

The present work analyzes the weekly load fluctuation, internal and external, throughout a season in a professional basketball team. To analyze the internal load factor, the session Rate of Perceived Exertion (sRPE) has been used, and the Integral Analysis System of Training Tasks (SIATE) has been used to monitor the external load. This is the first work that analyzes the complementary use of these two low-cost load monitoring tools. Firstly, the scores distribution obtained in both tests has been characterized. Secondly, an important and positive correlation was found since the association between the scores in sRPE and SIATE shows to increase together. Finally, we compared the scores of the study groups corresponding to the weeks without match (0-g), with one match (1-g) and with two matches (2-g) in each of the variables. Regarding sRPE, differences have been found between 0-g and 2-g, and between 1-g and 2-g. Furthermore, we observed differences in SIATE between 0-g and 1-g, 1-g and 2-g, and between 0-g and 2-g. Taken altogether, our study suggests that the complementary use of sRPE and SIATE is an effective and methodical system of monitoring training.

***Key words**: session Rate of Perceived Exertion, Integral Analysis System of Training Tasks, internal load, external load, weekly load fluctuation*

Introduction

Basketball is a team sport marked by intermittent high intensity and short-lasting efforts, which alternate with periods of low to moderate activity (Stojanović, Stojiljković, Scanlan, Dalbo, Berkelmans, & Milanović, 2018). The key biomechanical movements in basketball performance include sprints, accelerations, jumps, decelerations, lateral movements and changes of direction (Paulauskas, Kreivyte, Scanlan, Moreira, Siupsinskas, & Conte, 2019; Scanlan, Went, Tucker, & Dalbo, 2014). The average distance traveled during elite matches varies depending on the references consulted, covering ranges from 1.9 km to 6.3 km (Schelling & Torres-Ronda, 2013). The average intensity is above the lactate threshold, that is 5.1 ± 1.3 mmol/l with heart rate reaching 85% of the maximum possible, between 150 and 170 beats per minute (bpm) (Edwards, Spiteri, Piggott, Bonhotal, Haff, & Joyce, 2018).

The basketball season along with other sports such as football, rugby or volleyball, is one of the longest competitions in sports. A team competing in the NBA plays an average of 82 regular league games (Taylor, Chapman, Cronin, Newton, & Gill, 2012), while a Euroleague team can play up to 70 games, considering double competition between Europe and the National League (Svilar, Castellano, & Juckic, 2018).

In order to adjust training loads, it is necessary to know competitive demands and basketball games density that a team faces. Thus, a detailed understanding of the game calendar and scheduling training loads according to the weekly needs (one, two or even three games a week) will be essential to control both acute and chronic workloads (Gabbett, 2020; Manzi, D'ottavio, Impellizzeri, Chaouachi, Chamari, & Castagna, 2010).

The session Rate of Perceived Exertion (sRPE) is a reliable and valid tool, affordable and very easy to implement to monitor training loads in team sports (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004; Lambert & Borresen, 2010). Piedra, Peña, and Caparrós (2021) reported weekly average internal load values (sRPE) between 2250 and 5058 arbitrary units (AU). Manzi et al. (2010) characterized this load based on the number of weekly matches: 3334±256 AU for weeks without competition, 2928±303 AU for weeks with one match, and 2928±303 AU for weeks with two or more matches.

In professional sport, controlling training load is relevant to optimize performance (Akenhad & Nassis, 2015; Drew & Finch, 2016; Gabbett, 2004; Hulin, Gabbett, Caputi, Lawson, & Sampson, 2016) and reduce injury risks, especially those to soft tissues and/or without contact (Soligard, et al., 2016). In elite teams, the number of injuries is around 23 incidents per season (Piedra, et al., 2021). Thus, an improved load control may help to obtain a better understanding of the athletes' responses to training, their recovery needs, and their fatigue status. The highest levels of fatigue and injuries are associated with high peak loads in highly dense competitive calendars (Edwards, et al., 2018), for which it is estimated that basketball players need between 24-48 hours of post-match recovery before the next high intensity training session.

The same dose of training (external load) will generate different physiological responses (internal load) in the athletes' bodies (Lambert & Borresen, 2010), depending on their playing profile, playing position, age, injury history, and level of physical condition. For this reason, appropriate monitoring in the prescription of individualized external loads is necessary (Fox, Scanlan, & Stanton, 2017). Importantly, it is worth considering that the training methodology has been shown to explain between 24-100% of the variation in internal-external load relationships (McLaren, Macpherson, Coutts, Hurst, Spears, & Weston, 2017).

A statistically significant correlation has been found between the data collected using the comprehensive task analysis system in training known as SIATE (Ibáñez, Feu, & Cañadas, 2016), the Player Load variable (PL) collected by inertial devices, and the percentage of maximum heart rate (%MHR). Reina, Mancha-Triguero, García-Santos, García-Rubio, and Ibáñez (2019) confirmed the direct relationship of low-cost SIATE with inertial monitoring systems (for external load control) and heart rate devices (for internal load). Furthermore, the strong correlation found by Svilar et al. (2018) between internal load (sRPE) and external load (PL) in professional basketball players justifies the use of sRPE as a load control indicator in intermittent impact sports.

Based on the above, the objective of this study was to analyze the fluctuation of both internal and external weekly loads throughout a season in a professional basketball team. Specifically, the aim was to: 1) characterize the distributions of the scores obtained in the sRPE and SIATE; 2) study the association between the scores achieved in the sRPE and SIATE; 3) make a comparison between the scores of the groups corresponding to the weeks without a match (0-g), with one match (1-g) and with two matches (2-g) in each of the variables of sRPE and SIATE.

Methods

In the current research, the retrospective descriptive study, records of 280 training sessions practiced between August 2020 and May 2021 were used. The 2020/2021 season was seriously impacted by the global pandemic of COVID-19, which caused multiple matches to be postponed and several changes in work plan to be made. All mesocycles presented had the same structure (Table 1), composed of 5 microcycles, which could be microcycles without a match (0-g) (n=8), regular microcycles with a single match (1-g) (n=17), or congested microcycles with two or more matches (2-g) (n=15).

Participants

Participants in this research were members of a professional team (Bilbao Basket) that played two competitions during the period analyzed: the main professional basketball league in Spain (Liga Endesa) and the Basketball Champions League (European competition). Throughout the season analyzed, up to 20 professional basketball players made up the team's roster, but only seven of them were part of the final sample. Like in Clemente et al. (2019), the inclusion criteria necessary to be part of the final analysis were: a) completing 80% of the total mesocycles; b) carrying out 80% of the sessions of the corresponding mesocycle; and c) passing the medical examination that accredits athletes to be able to exercise at a professional level.

The study was conducted in accordance with the Declaration of Helsinki and included the club's authorization, participants' informed consent and a favorable report from the ethics committee of the University of La Rioja (file no. 76529).

Procedure

The sRPE was used to analyze the internal load factor. The questionnaire on perceived exertion (RPE) was quantified from 1 to 10 in two categories: a) muscular level: 1= rest, 5= challenging, 10= maximum; b) cardiovascular level: 1 = easy, 5 = intense, 10 = breathless. This categorization provides more precise information on the characteristics of the effort and the potential risk of injury mechanisms (Jones, Griffiths, & Mellalieu, 2017; Los Arcos, 2014). The final result is obtained from the average of the muscular and cardiovascular variables. This questionnaire was completed individually 15-45 minutes after finishing the training session (Clemente, et al. 2007), using the TeamBuildr Training software (TeamBuildr, Silver Spring, MD, USA), where each player had their own

Table 1. Timeline of the study shows sessions from the 2021/2022 season

Mesocycle 1	Week 1	Week 2	Week 3	Week 4	Week 5	Total
No. of games	0	1	2	1	2	6
No. of team practices	10	9	9	7	5	40
Total	10	10	11	8	7	46
Mesocycle 2	Week 6	Week 7	Week 8	Week 9	Week 10	Total
No. of games	1	2	1	1	0	5
No. of team practices	7	6	7	6	7	33
Total	8	8	8	7	7	38
Mesocycle 3	Week 11	Week 12	Week 13	Week 14	Week 15	Total
No. of games	0	2	2	2	1	7
No. of team practices	7	7	6	6	2	28
Total	7	9	8	8	3	35
Mesocycle 4	Week 16	Week 17	Week 18	Week 19	Week 20	Total
No. of games	0	2	2	1	2	7
No. of team practices	8	6	5	7	2	28
Total	8	8	7	8	4	35
Mesocycle 5	Week 21	Week 22	Week 23	Week 24	Week 25	Total
No. of games	2	1	2	1	2	8
No. of team practices	4	6	5	5	5	25
Total	6	7	7	6	7	33
Mesocycle 6	Week 26	Week 27	Week 28	Week 29	Week 30	Total
No. of games	1	0	0	1	1	3
No. of team practices	5	5	5	5	6	26
Total	6	5	5	6	7	29
Mesocycle 7	Week 31	Week 32	Week 33	Week 34	Week 35	Total
No. of games	1	1	1	1	0	4
No. of team practices	4	5	6	5	5	25
Total	5	6	7	6	5	29
Mesocycle 8	Week 36	Week 37	Week 38	Week 39	Week 40	Total
No. of games	1	2	0	2	3	8
No. of team practices	6	6	4	5	5	27
Total	7	8	5	7	8	35

user account. Once the player's RPE assessment was completed, the sRPE (or RPE of the session) was calculated, relating the resulting value of the player's average RPE (subjective nature) multiplied by the useful minutes of practice (objective nature). To obtain the sRPE, the initial and final part of the session were not included at the time of the calculation. The results obtained were expressed in arbitrary units (AU) (Reina, et al., 2019; Scanlan, et al., 2014).

To monitor the external load, the integral analysis system of training task (stands for SIATE in Spanish) was used. This is a monitoring system characterized by being universal, standardizable, modular and flexible (Ibáñez, et al., 2016). This tool controls six variables: degree of opposition, task density, number of simultaneous performers, competitive load, game space, and cognitive involvement. These variables are classified from 1 to 5 (5 being assigned as the highest load), which allows strength and conditioning coaches to easily evaluate the load quantitatively. From the aforementioned variables, other secondary variables emerge, such as the task load, explained as the sum of the value assigned to each of the six primary parameters (from 1 to 5 points) which ranges from 6 to 30 AU, and the load of the task for useful practice time. This parameter has been shown to more accurately reflect the actual load of the task (Fuster, Caparrós, & Capdevila, 2021; Reina, et al., 2019). Furthermore, this tool enables an objective control of the external load in training for contexts where economic and technological resources are limited. As with the internal load control, the time of the initial and final part of the session was not used for the calculation of the total SIATE of the session.

Data analysis

The data analysis was divided into two sections. The objective of the first section was to analyze the relationship between the sRPE and SIATE variables. To this end, the statistical significance of the association between the tests was determined by calculating the Pearson correlation coefficient, since the variables were considered quantitative, showing a linear relationship, and following a normal distribution. Interpretation of the data was performed following the criteria established by Cohen (1988, as cited in Hopkins, Marshall, Batterham, & Hanin, 2009). According to the aforementioned criteria, values close to 0.10 indicate a small relationship, those near 0.30 indicate a medium relationship, and those around 0.50 suggest a large relationship. In addition, this analysis was completed with the representation of the variability of the standardized Z scores in order to determine the joint distance of the values obtained in the variables under analysis.

Next, in the second block, the purpose of the analysis focused on evaluating whether the mean values in the sRPE and SIATE variables showed statistically significant differences depending on the number of matches played each week. Thus, a global analysis of variance for independent samples was carried out in which the Brown-Forsythe contrast statistics was calculated (Brown & Forsythe, 1974), given that non-compliance with the assumption of homogeneity of variances between groups using Levene's test. To evaluate the magnitude of the effect, the eta squared statistics (η^2) was calculated. Once the statistical significance of the differences between the group averages in both variables was verified, the t-test for means' contrast was applied, with the Bonferroni correction, to know at what levels these differences occur. The effect size of the contrasts carried out was analyzed using Cohen's d statistics, where values around 0.20 indicate a small effect size, those close to 0.50 are considered medium, and equal to or greater than 0.80 are interpreted as large (Cohen, 1988, as cited in Hopkins, Marshall, Batterham, & Hanin, 2009). The statistical analysis of the data were carried out using the IBM-SPSS-27 program.

Results

Descriptive statistics of the variables

Figure 1 presents descriptive data illustrating fluctuations of direct scores across weeks for both sRPE and SIATE variables. In relation to the sRPE variable, the average value was 2140.92 ± 791.99 AU. The coefficient of variation was 0.37, the highest weekly load was 4152 AU in week 28, while the lowest was 256 AU in week 15. Regarding the SIATE variable, the average has been located at 6679.76 ± 1893.61 AU. The coefficient of variation was 0.28. In this case, the highest weekly load was 4152 AU in week 11, and the lowest was 2019 AU in week 15. Finally, the comparison of the coefficients of variation revealed greater variability in the scores of the sRPE variable.

Association between the variables

On the other hand, the Pearson correlation between the scores obtained in sRPE and SIATE were both statistically significant (r = 0.721; p<.01),

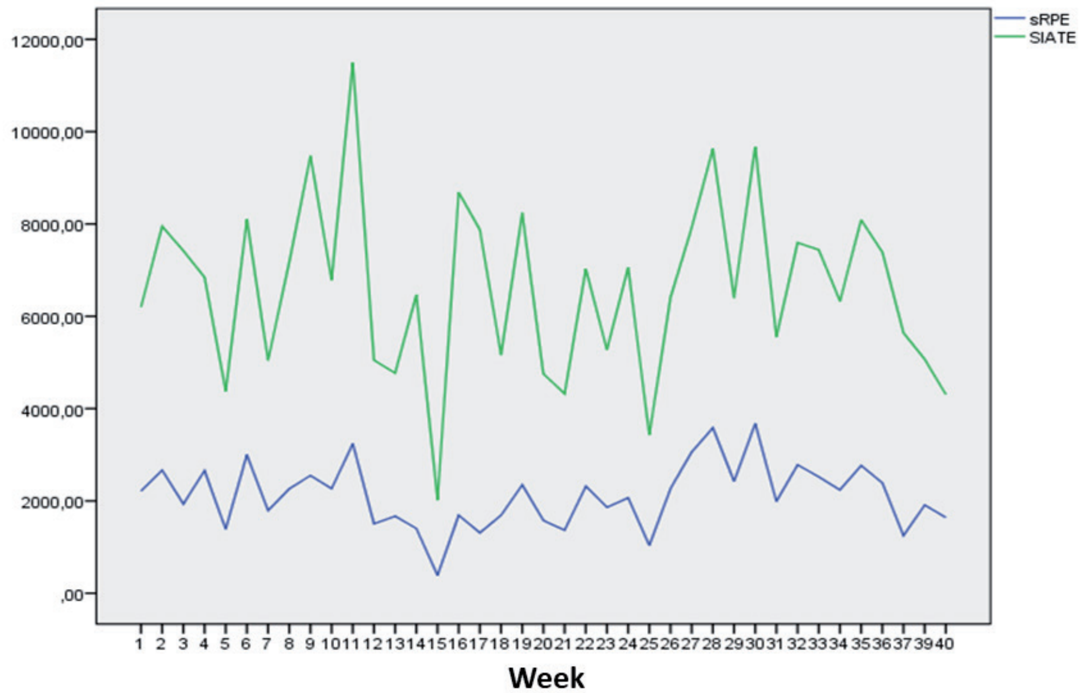


Figure 1. Fluctuation of the sRPE and SIATE variables between weeks throughout the season expressed in direct scores.

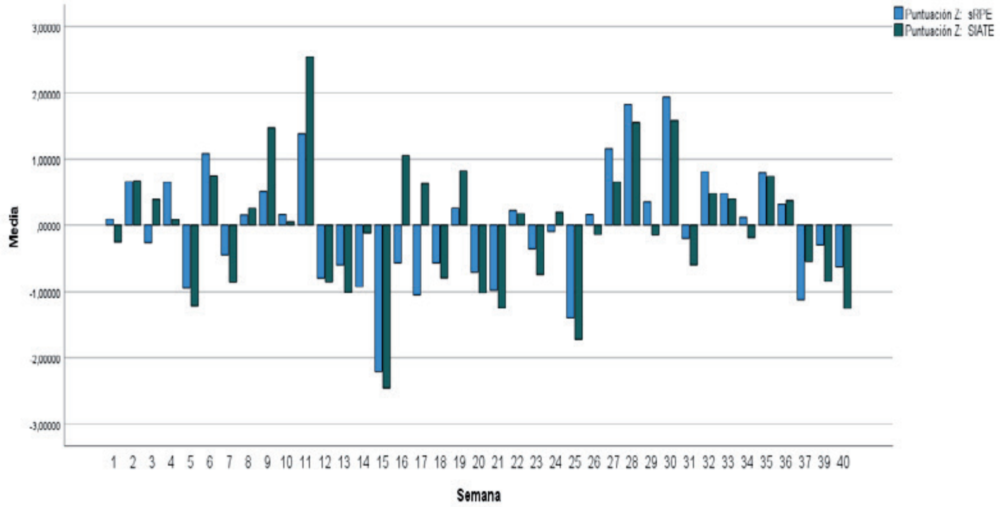


Figure 2. Fluctuation of the variability of the standardized Z scores of the sRPE and SIATE variables between weeks throughout the season.

Table 2. Group contrasts

	sRPE				SIATE			
	Mean ± SD	0-g vs. 1-g	0-g vs. 2-g	1-g vs. 2-g	Mean ± SD	0-g vs. 1-g	0-g vs. 2-g	1-g vs. 2-g
0-g	2364.11±954.41	p=.188 d=0.306	p<.001 d=1.612	p<.001 d=1.306	7984.88±1909.70	p=.002 d=0.568	p<.001 d=1.661	p<.001 d=1.093
1-g	2390.98±743.30				7079.34±1680.73			
2-g	1532.90±446.89				5336.15±1216.26			

Note. d = Cohen's d; 0-g = no game per week; 1-g = one game per week; 2-g = two games per week.
* Significant differences (n.s. 0.01)

indicating a large and direct relationship. In this regard, the weeks with higher values in the sRPE variable corresponded to weeks with higher levels in the SIATE variable, as shown in Figure 2. One of the reasons was that the trend of this relationship was altered along eight weeks, where the association was reversed. Specifically, in weeks 1, 26 and 29, while the players assigned positive values to the sRPE variable, these corresponded to low values in the SIATE variable. In contrast, during weeks 3, 16, 17, 24 and 34, the association was found of opposite nature: high values in the sRPE variable were associated with low values in the SIATE variable.

Contrast between the groups

The analysis of variance test for the global contrast of independent samples was found to be statistically significant for both the sRPE ($p<.001$; $\eta^2 = 0.297$) and SIATE ($p<.001$; $\eta^2 = 0.317$) variables between the corresponding groups of 0-g, 1-g, and 2-g.

In the pairwise comparison, as detailed in Table 2, the mean contrast test for independent groups determined the existence of statistically significant differences between the groups: 0-g and 2-g (p=.018; d = 1.612) and 1-g and 2-g (p<.001; d = 1.306) in the sRPE variable. In relation to the SIATE variable, statistically significant differences were present between 0-g and 1-g (p=.002; d = 0.568), 0-g and 2-g (p<.001; d = 1.661), and 1-g and 2-g (p<.001; d = 1.093). Likewise, the size effect of the differences that were statistically significant occurred when comparing between 0-g and 1-g in the SIATE variable and high in the rest of the contrasts.

Discussion and conclusions

The objective of this research was to analyze the fluctuations of both internal and external weekly loads using sRPE and the integral analysis system of training tasks (SIATE), respectively, in a professional basketball team throughout a season (Ibáñez, et al., 2016). To the best of authors' knowledge, this is the first research that analyzes the complementary use of these two low-cost load monitoring tools in men's professional basketball.

We first characterized the distribution of the scores obtained in the sRPE and SIATE, revealing a notable fluctuation in the load, especially in relation to the sRPE, throughout the season, in line with the results obtained by Manzi et al. (2010) and Salazar, García, Svilar, and Castellano (2021). The highest average sRPE values corresponded to 1-g and the lowest to 2-g; while for SIATE the highest mean values occurred in 0-g and the lowest mean values were assigned to 2-g. Consistent with Svilar et al. (2018) and Paulauskas et al. (2019), we found that high competitive density (two games per week) reduces the time available to schedule training sessions sufficiently far from the competition to ensure players' recovery, which was reflected in the decrease in the training load in both the sRPE and SIATE. During weeks without competition the training load was higher due to a greater gap between matches and the need to maintain the competitive pace.

Secondly, the association between the sRPE and SIATE scores achieved has been studied. The positive and large correlation between internal and external load detected in the present study corresponds to previous research that has explored this connection among other sports (Reina, et al., 2019). Positive and important correlation has been found between the sRPE and SIATE scores ($r = 0.721$) since the values of both variables tend to increase together. Previous studies examined the relationship between external load, evaluated through variables such as Player Load, and the subjective perception of effort in different sports (Kniubaite, Skarbalius, Clemente, & Conte, 2019; Svilar, et al., 2018). Furthermore, positive correlations have been found between external load and physiological parameters, such as heart rate, which helped to understand the adaptive physical response to training (Reina, et al., 2019; Scanlan, et al., 2014). In line with these studies, our measurement tools have proven to be sensitive to load fluctuation over the course of a season and displayed to be strong.

Finally, a comparison was made between the scores of the groups corresponding to the weeks without game, to those with one game, and those with two games in each of the sRPE and SIATE variables. In relation to sRPE, differences were found between 0-g and 2-g and between 1-g and 2-g, supporting the impact that competitive density has on the weekly load (Piedra, et al., 2021). The values of internal (sRPE) and external (SIATE) load during weeks without competition and weeks with one game were higher than those obtained during weeks of higher competitive density (two or more games), coinciding with the results of researchers who showed the same trend for internal load (Manzi, et al., 2010) and external load (Salazar, et al., 2020).

The comparative analysis for the SIATE showed significant differences between 0-g and 1-g; 1-g and 2-g; and between 0-g and 2-g. Interestingly, these contrasts between 0-g, 1-g, and 2-g have not been carried out for SIATE till now (Ibáñez, et al., 2016). Our findings support the use of this load monitoring tool, which has proven to be: universal – because it is implemented in a basic Office application, spreadsheet type; standardizable – thanks to the classification of each of the categories of its basic variables, which allows comparing data from different teams and sports levels; modular – since the amount of information that coaches can record in each training task can be defined; and flexible – as it presents various variables with multiple classification categories.

Finally, our results agree with those obtained in previous investigations (Aoki, et al., 2016; McLaren, et al., 2018; Scanlan, et al., 2014) that used other load monitoring tools such as sRPE, TRIMP and accelerometers, confirming significant differences found between the variables based on the number of matches per week (Manzi, et al., 2010). Our findings indicate that both the external load (SIATE) and the player's perception of effort (sRPE) are sensitive to differentiate between weeks with different numbers of matches. The relationship between external and internal load depending on the different competitive density is a key aspect in considering training programming to optimize performance and well-being of players (Conte, Kolb, Scanlan, & Santolamazza, 2018). The results of this research corroborate the complex nature of load management in professional basketball (Salazar, et al., 2020; Svilar, et al., 2018).

In this article and for the first time with elite basketball players, the appropriateness has been demonstrated of using these two ecological tools that allow controlling both internal load (sRPE) and external load (SIATE) in a complementary way, thus making them an effective and methodical monitoring system. The use of both low-cost tools can help coaches and physical trainers to optimize sports performance and reduce the risk of injury not only in professional contexts but also in amateur teams with limited resources.

References

Akenhead, R., & Nassis, G.P. (2015). Training load and player monitoring in high-level football: Current practice and perceptions. *International Journal of Sports Physiology and Performance, 11*(5), 587-593. https://doi.org/10.1123/ijspp.2015-0331

Aoki, M.S., Ronda, L.T., Marcelino, P.R., Drago, G., Carling, C., Bradley, P.S., & Moreira, A. (2017). Monitoring training loads in professional basketball players engaged in a periodized training program. *The Journal of Strength and Conditioning Research, 31*(2), 348-358. https://doi.org/10.1519/JSC.0000000000001507

Brown, M.B., & Forsythe, A.B. (1974). The small sample behavior of some statistics which test the equality of several means. *Technometrics, 16*(1), 129-132. https://doi.org/10.1080/00401706.1974.10489158

Clemente, F.M., Mendes, B., Bredt, S.D.G.T., Praça, G.M., Silvério, A., Carriço, S., & Duarte, E. (2019). Perceived training load, muscle soreness, stress, fatigue, and sleep quality in professional basketball: A full season study. *Journal of Human Kinetics*, 67, 199-207. https://doi: 10.2478/hukin-2019-0002

Clemente, F.M., Mendes, B., Nikolaidis, P.T., Calvete, F., Carriço, S., & Owen, A.L. (2017). Internal training load and its longitudinal relationship with seasonal player wellness in elite professional soccer. *Physiology and Behavior*, 179, 262-267. https://doi.org/10.1016/j.physbeh.2017.06.021

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Academic Press.

Conte, D., Kolb, N., Scanlan, A.T., & Santolamazza, F. (2018). Monitoring training load and well-being during the in-season phase in national Collegiate Athletic Association Division I men's basketball. *International Journal of Sports Physiology and Performance*, *13*(8), 1067-1074. https://doi.org/10.1123/ijspp.2017-0689

Drew, M.K., & Finch, C.F. (2016). The relationship between training load and injury, illness and soreness: A systematic and literature review. *Sports Medicine*, *46*, 861-883. https://doi.org/10.1007/s40279-015-0459-8

Edwards, T., Spiteri, T., Piggott, B., Bonhotal, J., Haff, G.G., & Joyce, C. (2018). Monitoring and managing fatigue in basketball. *Sports*, *6*(1), 19. https://doi.org/10.3390/sports6010019

Fox, J.L., Scanlan, A.T., & Stanton, R. (2017). A review of player monitoring approaches in basketball: Current trends and future directions. *The Journal of Strength and Conditioning Research, 31*(7), 2021-2029. https://doi.org/10.1519/jsc.0000000000001964

Fuster, J., Caparrós, T., & Capdevila, L. (2021). Evaluation of cognitive load in team sports: Literature review. *PeerJ*, *9*, e12045. https://doi.org/10.7717/peerj.12045

Gabbett, T.J. (2004). Influence of training and match intensity on injuries in rugby league. *Journal of Sports Sciences*, *22*(5), 409-417. https://doi.org/10.1080/02640410310001641638

Gabbett, T.J. (2020). How much? How fast? How soon? Three simple concepts for progressing training loads to minimize injury risk and enhance performance. *Journal of Orthopaedic and Sports Physical Therapy*, *50*(10), 570-573. https://doi.org/10.2519/jospt.2020.9256

Hopkins, W.G., Marshall, S.W., Batterham, A.M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Hulin, B.T., Gabbett, T.J., Caputi, P., Lawson, D.W., & Sampson, J.A. (2016). Low chronic workload and the acute: Chronic workload ratio are more predictive of injury than between-match recovery time: A two-season prospective cohort study in elite rugby league players. *British Journal of Sports Medicine*, *50*(16), 1008-1012. http://dx.doi.org/10.1136/bjsports-2015-095364

Ibáñez, S.J., Feu, S., & Cañadas, M. (2016). Sistema integral para el análisis de las tareas de entrenamiento, SIATE, en deportes de invasión. [Integral analysis system of training tasks, SIATE, in invasion games.] *E-balonmano.com: Revista de Ciencias del Deporte*, *12*(1), 3-30.

Impellizzeri, F.M., Rampinini, E., Coutts, A.J., Sassi, A.L.D.O., & Marcora, S.M. (2004). Use of RPE-based training load in soccer. *Medicine and Science in Sports and Exercise*, *36*(6), 1042-1047. https://doi.org/10.1249/01.mss.0000128199.23901.2f

Jones, C.M., Griffiths, P.C., & Mellalieu, S.D. (2017). Training load and fatigue marker associations with injury and illness: A systematic review of longitudinal studies. *Sports Medicine*, *47*, 943-974. https://doi.org/10.1007/s40279-016-0619-5

Kniubaite, A., Skarbalius, A., Clemente, F.M., & Conte, D. (2019). Quantification of external and internal match loads in elite female team handball. *Biology of Sport*, *36*(4), 311-316. https://doi.org/10.5114/biolsport.2019.88753

Lambert, M.I., & Borresen, J. (2010). Measuring training load in sports. *International Journal of Sports Physiology and Performance*, *5*(3), 406-411. https://doi.org/10.1123/ijspp.5.3.406

Los Arcos, A. (2014). *Control y evaluación de la carga de entrenamiento para la preparación física de jóvenes futbolistas profesionales.* (Doctoral thesis, University of the Basque Country). Faculty of Physical Activity and Sport Sciences.

Manzi, V., D'ottavio, S., Impellizzeri, F.M., Chaouachi, A., Chamari, K., & Castagna, C. (2010). Profile of weekly training load in elite male professional basketball players. *The Journal of Strength and Conditioning Research*, *24*(5), 1399-1406. https://doi.org/10.1519/jsc.0b013e3181d7552a

McLaren, S.J., Macpherson, T.W., Coutts, A.J., Hurst, C., Spears, I.R., & Weston, M. (2018). The relationships between internal and external measures of training load and intensity in team sports: A meta-analysis. *Sports Medicine*, *48*, 641-658. https://doi.org/10.1007/s40279-017-0830-z

Paulauskas, H., Kreivyte, R., Scanlan, A.T., Moreira, A., Siupsinskas, L., & Conte, D. (2019). Monitoring workload in elite female basketball players during the in-season phase: Weekly fluctuations and effect of playing time. *International Journal of Sports Physiology and Performance*, *14*(7), 941-948. https://doi.org/10.1123/ijspp.2018-0741

Piedra, A., Peña, J., & Caparrós, T. (2021). Monitoring training loads in basketball: A narrative review and practical guide for coaches and practitioners. *Strength and Conditioning Journal*, *43*(5), 12-35. https://doi.org/10.1519/SSC.0000000000000620

Reina, M., Mancha-Triguero, D., García-Santos, D., García-Rubio, J., & Ibáñez, S.J. (2019). Comparación de tres métodos de cuantificación de la carga de entrenamiento en baloncesto. [Comparison of three methods for quantifying basketball training load.] *RICYDE. Revista Internacional de Ciencias del Deporte*, *15*(58), 368-382. https://doi.org/10.5232/ricyde2019.05805

Salazar, H., Garcia, F., Svilar, L., & Castellano, J. (2021). Physical demands in three different basketball competitions played by the same under-18 players. *Montenegrin Journal of Sports Science and Medicine*, *10*(2), 59-64. https://doi.org/10.26773/mjssm.210909

Salazar, H., Svilar, L., Aldalur-Soto, A., & Castellano, J. (2020). Differences in weekly load distribution over two Euroleague seasons with a different head coach. *International Journal of Environmental Research and Public Health*, *17*(8), 2812. https://doi.org/10.3390/ijerph17082812

Scanlan, A.T., Wen, N., Tucker, P.S., & Dalbo, V.J. (2014). The relationships between internal and external training load models during basketball training. *The Journal of Strength and Conditioning Research*, *28*(9), 2397-2405. https://doi.org/10.1519/JSC.0000000000000458

Schelling, X., & Torres-Ronda, L. (2013). Conditioning for basketball: Quality and quantity of training. *Strength and Conditioning Journal*, *35*(6), 89-94. https://doi.org/10.1519/SSC.0000000000000018

Singh, F., Foster, C., Tod, D., & McGuigan, M.R. (2007). Monitoring different types of resistance training using session rating of perceived exertion. *International Journal of Sports Physiology and Performance, 2*(1), 34-45. https://doi.org/10.1123/ijspp.2.1.34

Soligard, T., Schwellnus, M., Alonso, J.M., Bahr, R., Clarsen, B., Dijkstra, H. P., ..., & & Engebretsen, L. (2016). How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *British Journal of Sports Medicine*, *50*(17), 1030-1041. https://doi.org/10.1136/bjsports-2016-096581

Stojanović, E., Stojiljković, N., Scanlan, A.T., Dalbo, V.J., Berkelmans, D.M., & Milanović, Z. (2018). The activity demands and physiological responses encountered during basketball match-play: A systematic review. *Sports Medicine*, *48*, 111-135. https://doi.org/10.1007/s40279-017-0794-z

Svilar, L., Castellano, J., & Jukić, I. (2018). Load monitoring system in top-level basketball team: Relationship between external and internal training load. *Kinesiology*, *50*(1), 25-33. https://doi.org/10.26582/k.50.1.4

Taylor, K., Chapman, D., Cronin, J., Newton, M.J., & Gill, N. (2012). Fatigue monitoring in high performance sport: A survey of current trends. *Journal of Australian Strength and Conditioning, 20*(1), 12-23.

Submitted: February 12, 2024
Accepted: April 28, 2024
Published Online First: December 11, 2024

Correspondence to:
Daniel Lapresa, Ph.D.
Edificio Vives (Universidad La Rioja)
C/ Luis de Ulloa s/n. 26004
Logroño, La Rioja – Spain
Phone: +34 941299282
E-mail: daniel.lapresa@unirioja.es

VARIABLES USED FOR TALENT IDENTIFICATION AND DEVELOPMENT IN SOCCER: A SCOPING REVIEW

Valmir O. Silvino[1,2], Cirley P. Ferreira[1,2], Pedro Figueiredo[3,4], Luciano S. Prado[5], Bruno P. Couto[6], Guilherme A. Pussieldi[7], Sandro S. Almeida[8,9,10], Danilo M. L. Prado[11,12], and Marcos A. P. Santos[1,2]

[1]Department of Biophysics and Physiology, Nucleus of Study in Physiology Applied to Performance and Health (NEFADS), Federal University of Piaui, Teresina, Piauí, Brazil
[2]Rede Nordeste de Biotecnologia (RENORBIO), Federal University of Piauí, Teresina, Piauí, Brazil
[3]Physical Education Department, College of Education, United Arab Emirates University, Al Ain, Abu Dhabi, United Arab Emirates
[4]Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, Covilhã, Portugal
[5]Federal University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil
[6]University of the Sunshine Coast, Sippy Downs, Queensland, Australia
[7]Federal University of Viçosa, Viçosa, Minas Gerais, Brazil
[8]Department of Obstetrics, Escola Paulista de Medicina, Universidade Federal de São Paulo (UNIFESP), São Paulo, SP, Brazil
[9]Hospital Israelita Albert Einstein, São Paulo, SP, Brazil
[10]Faculdade Anhanguera de Guarulhos, Guarulhos, SP, Brazil
[11]School of Medicine, University of São Paulo, São Paulo, Brazil
[12]Ultra Sports Laboratory, São Paulo, Brazil

Review
DOI 10.26582/k.56.2.9

Abstract:

Talent identification and development in youth soccer are complex and multidimensional processes. This scoping review aimed to explore the current literature regarding the variables used in the talent identification and development process in soccer. This study was developed referring to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) guidelines. Pubmed, Web of Science and Scopus databases were searched from September to October 2023. Only peer-reviewed journal articles published in English were included, with no limitation regarding the publication year. Through the initial search 774 records were identified and 190 articles met the inclusion criteria. The main finding was that most studies assessed speed (52.1%), maturity (42.1%), lower limbs strength (40.5%), aerobic capacity (35.8%), agility (32.6%), technical skills (16.8%), and tactical skills (14.2%). Male athletes were investigated in 162 studies (85.3%), whereas seven studies (3.7%) were conducted with females only, and seven articles (3.7%) with males and females. Fourteen studies (7.4%) did not specify the sex of the participants. In conclusion, findings indicate that physical performance and maturity factors are the most investigated variables regarding talent identification and development in soccer. This review highlights the importance of considering physical performance tests and technical/tactical skills, along with maturity status assessment, as key tools in talent identification programmes. Current talent identification practices in soccer may benefit from a more balanced approach that includes physical, technical, tactical, maturational, and psychological assessments to capture a broader range of player potential.

Key words: *young athletes, football, talent, youth development*

Introduction

Talent is regarded as a natural and exceptional ability that may lead to outstanding results, and talent identification in soccer has been defined as the recognition process of individuals with the potential to become first class players (Williams & Reilly, 2000). In soccer, talent is often understood as a multifaceted concept involving various qualities that influence performance, such as physical, physiological, technical, and tactical skills, alongside psychological and social factors (Larkin & O'Connor, 2017). Talent identification process is the recognition of young players with the potential to join a development programme involving coaching, support, training, and match-play (Vaeyens, Güllich, Warr, & Philippaerts, 2009). This is a multifactorial and complex process designed to assist coaches and researchers in sports academies in finding young athletes with the potential to achieve elite status (Bergkamp, Frencken, Niessen, Meijer, & den Hartigh, 2021). Talent identification and development allow for the inclusion of players from outside the game with the potential to advance in development programmes (Williams & Reilly, 2000). It has been suggested that a multidisciplinary approach should be explored to identify talented youth players by measuring some predictor variables, including physical, technical-tactical, maturity, and psychological factors (Williams, Ford, & Drust, 2020).

Soccer is considered the world's leading sport in terms of participation, licenses, spectatorship, financial resources, and revenues (Bourke, 2003). Therefore, millions of youth players participate in systematic selection programmes in professional soccer academies worldwide (Ford, et al., 2020). Detecting young talent for soccer has become an issue in recent years (Bergkamp, Niessen, den Hartigh, Frencken, & Meijer, 2019). Recruitment at an early stage in a soccer academy is crucial for the long-term development of a player (Ford, et al., 2020). Soccer scouts are constantly looking for talented young players to develop elite players. This has led to a growing number of evaluation tools for talent identification and development in soccer (Pino-Ortega, Rojas-Valverde, Gómez-Carmona, & Rico-González, 2021).

Many reviews have been written on talent identification in soccer (Fernández-Rio & Méndez-Giménez, 2014; Focan, Paraschiv, & Zamfir, 2018; Sarmento, Anguera, Pereira, & Araújo, 2018; Williams, 2020; Williams & Reilly, 2000). However, there are gaps in the literature regarding the main variables assessed by researchers and exercise scientists in investigations related to the talent identification and development process in soccer. The rationale for conducting this scoping review lies in the increasing recognition of the complex and multifactorial nature of talent in soccer, where physical, technical, tactical, psychological, and sociological factors all play critical roles in player's success. As youth soccer talent identification becomes more central to the development of elite players, understanding which variables are most frequently assessed becomes essential. Therefore, this scoping review aims to identify the main variables assessed in studies regarding talent identification and development in soccer.

Methods

Search strategy

This scoping review has been previously registered at OSF Registries (https://osf.io/beqyh/). A systematic literature search was carried out on PubMed (n = 201), Web of Science (n = 235), and Scopus (n = 338) databases from September to October 2023 by two authors (VOS and CPF). Gray literature was considered via Google Scholar. We searched for additional records through cross-referencing to avoid missing any possible relevant source. The search strategy was performed following the Preferred Reporting Items for Systematic review and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) Checklist (Tricco, et al., 2018), including the PICO strategy: P (participants) (e.g., student, adolescent, child, young); I (intervention) (programme, intervention); C (comparators) (e.g., football, soccer, "sport context"); O (outcomes) (e.g., identification, detection, selection, development). The complete strategy used for searching databases previously mentioned is shown in Supplementary File 1.

Inclusion and exclusion criteria

The primary data from the articles, including title, authors, date, and database, was extracted and organized in a Microsoft Excel spreadsheet (Microsoft Excel, Microsoft, Redmond, WA, USA). Following the removal of duplicate records, two authors (VOS and CPF) screened the search results independently and blindly, considering the inclusion/exclusion criteria established using the Rayyan website (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016). Any disagreements between the reviewers were resolved by consensus or arbitration through the third reviewer (MAPS). References that could not be eliminated by title or abstract alone were retrieved for further evaluation. In case of disagreements on the final iinclusion/exclusion status, the two authors responsible for the screening discussed and decided against its inclusion or exclusion. Only peer-reviewed journal articles published in English were included, regardless the publication year. Only studies involving soccer athletes, regardless of sex, were included. Studies in which the participants were older than 18 years were excluded. Abstracts, conference papers from annual meetings, and case studies were not included due to the need for additional information for the systematization process. Moreover, review articles, meta-analyses, pilot studies, clinical trials, association studies, and studies conducted with animal models were excluded.

Data extraction

Two authors (VOS and CPF) conducted the selection and information extraction from the studies included. The data extracted include study design, sample, variable evaluated, and evaluation tool. The data were systematized using methodological outcomes and the results of the studies. After independent screening, two researchers (VOS and CPF) discussed any differences and finalized the studies for inclusion in this review. Eventual conflicts of decisions were resolved by consensus or arbitration by the third author (MAPS). The outcomes were summarized, taking into account the author, publication year, sample size, and the evaluation tools employed in the talent identification and development process (see Supplementary File 2).

Quality assessment

We evaluated the quality of the cross-sectional studies using The Joanna Briggs Institute (JBI) Critical Appraisal Checklist for studies reporting prevalence data (Munn, MClinSc, Lisy, Riitano, & Tufanaru, 2015), and for longitudinal studies, the assessment was conducted with the Newcastle-Ottawa Quality Assessment Scale (Wells, Shea, O'Connell, & Peterson, 2000). Two reviewers assessed the quality of each article (VOS and CPF), with disagreements resolved by consensus or arbitration by the third reviewer (MAPS). The complete scores for the studies in this review are shown in Supplementary File 2.

The JBI Critical Appraisal Checklist comprises eight items, each scored as "Yes", "No", "Unclear", or "Not applicable". This checklist examines the potential for bias in three domains: (I) design, (II) conduct, and (III) analysis. Each article was assessed based on nine specific criteria: (Item 1) Was the sample frame appropriate to address the target population? (Item 2) Were study participants sampled in an appropriate way? (Item 3) Was the sample size adequate? (Item 4) Were the study subjects and the setting described in detail? (Item 5) Was the data analysis conducted with sufficient coverage of the identified sample? (Item 6) Were valid methods used for the identification of the condition? (Item 7) Was the condition measured in a standard, reliable way for all participants? (Item 8) Was there appropriate statistical analysis? (Item 9) Was the response rate adequate, and if not, was the low response rate managed appropriately? The overall appraisal was categorized as 'Include', 'Exclude' and 'Seek further info'.

The Newcastle-Ottawa Quality Assessment Scale consists of eight items grouped into three categories: (i) selection (1. Representativeness of the exposed cohort; 2. Selection of the non-exposed cohort [controls]; 3. Ascertainment of exposure, and 4. Demonstration that outcome of interest was not present at start of study), (ii) comparability (5. Comparability of cohorts on the basis of the design or analysis), and (iii) outcome (6. Assessment of outcome; 7. Was follow-up long enough for outcomes to occur? and 8. Adequacy of follow up of cohorts). For each study, the items from the selection and outcome categories were assessed with one star, and a maximum of two stars was used in the comparability category.

Results

Studies included

A total of 774 articles were initially retrieved from the databases used in this review, out of which 245 were excluded after duplicate removal. Additionally, 104 records were added after consulting the gray literature and through cross-referencing. A total of 529 articles were analyzed by reviewing the title, abstract, and year of publication considering the exclusion and inclusion criteria. Finally, 423 studies were read in their full-text version. Since they did not contemplate the purpose of this review, 233 studies were discarded. Thus, 190 articles were included (Figure 1).

Participants' characteristics

The sample size of the studies ranged from 10 (Zago, et al., 2016) to 68,158 (Höner, Votteler, Schmid, Schultz, & Roth, 2015). Considering the studies that described the average age of the participants, the sample included in this review was 13.3±0.8 years old. Although some studies did not specify the average age, they disclosed the minimum and maximum age, which ranged from three to 18 years. Out of the 162 studies on talent identification, 85.3% focused on male athletes, while only 3.7% involved females exclusively, and another 3.7% included both males and females. Additionally, 7.4% of the studies did not specify the participants' sex. Further details can be found in Supplementary File 2.

Studies' characteristics

Out of the 190 articles included in this scoping review, 99 evaluated the sprint performance, 80 investigated the maturity status, 77 evaluated the lower limbs strength, 68 investigated the aerobic capacity, and 62 examined the agility of their participants. In addition, technical skills, including passing, dribbling, controlling, heading, and kicking, were used in 32 studies and tactical

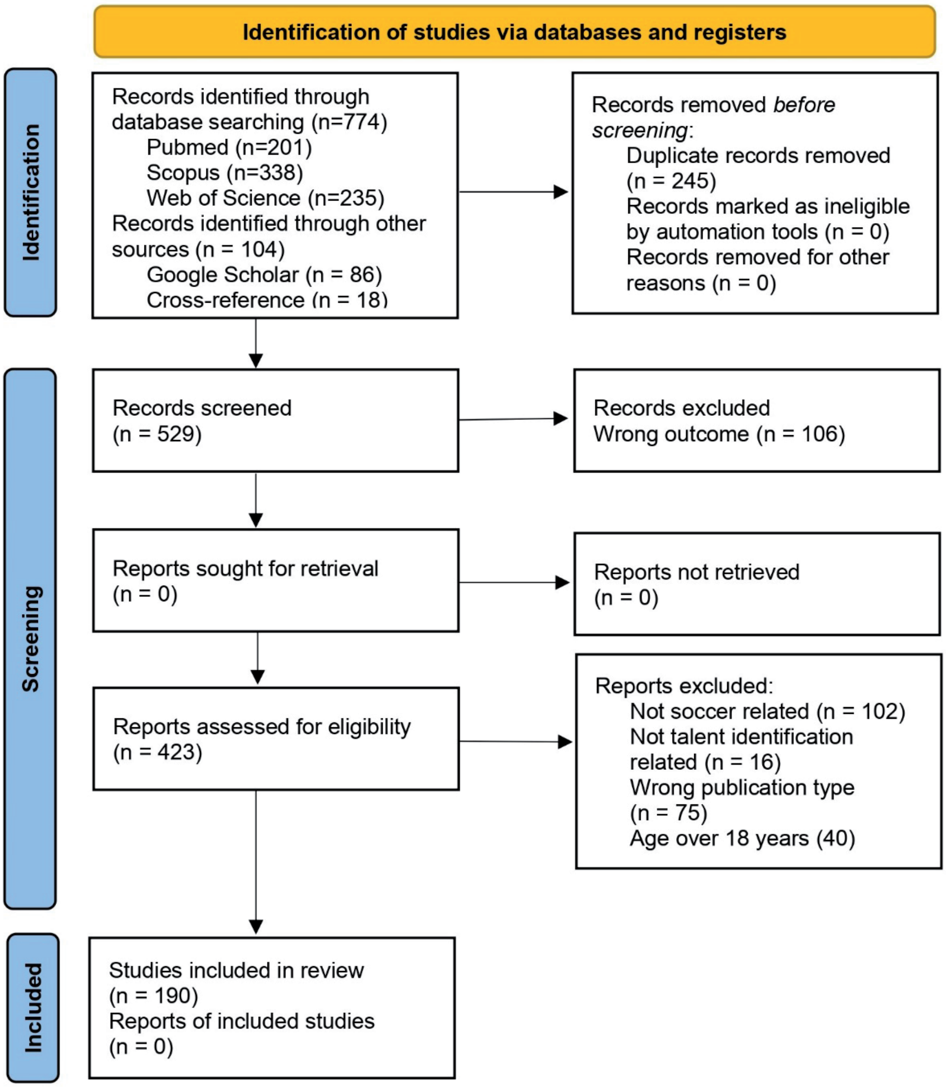


Figure 1. Search strategy flow diagram of the study

skills were evaluated in 27 studies, as seen in Figure 2. A cross-sectional design was employed in 80% of the studies, with the remaining 20% using a longitudinal design. The follow-up period of the longitudinal studies included in this review ranged from six months (Clemente, et al., 2021) to ten years (Craig & Swinton, 2021).

The cross-sectional studies met 78% to 100% of the quality criteria, with an average of 95%, as assessed by the JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies. Similarly, the longitudinal studies met 67% to 100% of the quality criteria, with an average of 81%, scoring six to eight stars according to the Newcastle-Ottawa Quality Assessment Scale. All the studies received an overall appraisal of 'include' (Supplementary file 2).

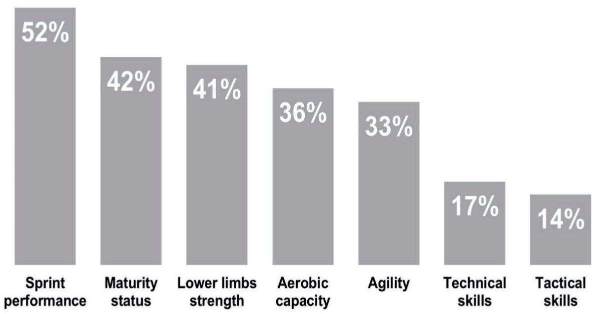


Figure 2. Distribution of variables assessed in talent identification studies included in this review

Discussion and conclusions

This study presented a review of the available literature on the talent identification and development of soccer players. The main finding of our study is that the majority of the studies focused on physical performance-related variables in talent identification and development in soccer. Sprint performance emerged as the most frequently evaluated metric, with 52.1% of the studies recognizing its significance. This reflects the widely acknowledged importance of speed in soccer, an attribute that can significantly influence the effectiveness on the field. Furthermore, maturity status and lower limbs strength were evaluated in 42.1% and 40.5% of the studies, respectively. These variables address fundamental aspects of a player's physical development. Lower limb power is crucial for shooting, tackling, and jumping. Likewise, assessing maturity status acknowledges the potential impact of growth and development trajectories on performance.

Not surprisingly, we observed that maturity status, physical performance, anthropometry, as well as technical and tactical skills were investigated in most of the studies in this review. Considering the specificity of soccer, the majority of the investigations assessed variables that closely replicate the demands of the game, including high-intensity running, agility, and rapid changes of direction.

It is worth mentioning that maturity can significantly impact the other variables considered in this review, particularly in the context of sports and exercise, including soccer (Hunter, et al., 2022). During adolescence, the body undergoes significant changes as it develops from a child to an adult, including increases in height, body mass, and muscle mass, as well as changes in bone density, hormonal levels, and other physiological systems (Malina, et al., 2018). As a result, physical abilities such as strength, speed, and endurance can improve dramatically during this time (Albaladejo-Saura, Vaquero-Cristóbal, González-Gálvez, & Esparza-Ros, 2021). Moreover, there can be individual differences in the timing and pace of physical maturation, with some individuals developing faster or slower than others (Albaladejo-Saura, et al., 2021). This can result in players of the same age having noticeably diverse physical characteristics, which, in turn, can affect how they perform in tests.

The predominance of physical performance parameters in talent identification for soccer research reflects several factors related to the sport's demands. Soccer relies heavily on physical abilities such as speed, strength, agility, and endurance, which are essential for performing actions like sprinting, tackling, jumping, and rapid changes of direction (Bidaurrazaga-Letona, Lekue, Amado, Santos-Concejero, & Gil, 2015). Moreover, physical performance metrics are relatively straightforward to assess using standardized field-based tests, which are often practical, affordable, and can be conducted with minimal equipment. Finally, the emphasis on physical performance is partly due to its high relevance in competitive play and the need for efficiency in identifying players who can perform well under the physical demands of soccer. However, as this review suggests, a more balanced approach, including technical, tactical, and maturational evaluations, may provide a more comprehensive insight into a player's potential beyond physical abilities.

Sprint performance

Sprint performance was the most evaluated variable in the studies included in this scoping review, present in 99 articles (52.1%). All the studies used practical field-based sprint tests to estimate this parameter. The primary test used for evaluating the sprint performance in the studies included in this review was the 30-m sprint test, used in 31 (31.3%) studies. Sprint ability plays a crucial role in soccer, accounting for around 11% of the total distance covered during a match (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). In addition, it has been reported that sprint performance can distinguish among youth soccer players of diverse levels of play (Comfort, Stewart, Bloom, & Clarkson, 2013). Similarly, it is widely recognized that sprint ability is strongly associated with lower body power in both elite soccer players (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004) and youth soccer athletes (Comfort, Stewart, Bloom, & Clarkson, 2014).

Maturity status

It was observed that maturity status was widely evaluated, being investigated in 42.1% of the studies included in this review. Among the methods used to assess the maturity status of the participants, the relative age effect (RAE) and the determination of the age at peak height velocity (PHV) stood out. RAE is a phenomenon that describes an unbalanced distribution of individuals within a group, where those born shortly after the established cut-off date gain certain advantages, while those born later face several disadvantages (Bilgiç & Işın, 2023). For instance, players born from January 1st to December 31st of a given year may be in the same age group. This means a player born in January could be a year older than a player born in December of the same year, which may pose an advantage for their immediate and long-term development in several contexts, including sports and education (Baker, Schorer, & Cobley, 2010). The competitive advantage observed in the older athletes in their age group results from the older athletes being more physically and emotionally mature (Helsen, et al., 2012).

PHV, which typically occurs during puberty, a period characterized by significant physical and hormonal changes, refers to the period during growth and development when individuals experience the fastest rate of longitudinal growth (Patel, Nevill, Cloak, Smith, & Wyon, 2019). Soccer players are expected to achieve their PHV for around one year between 10.7 and 15.2 years of age, accelerating their growth rate at approximately 7.5-9.7 cm/year (Philippaerts, et al., 2006). In soccer, biological maturation is regarded as the status, timing, and tempo of progress demanded to achieve maturity (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004). The age at PHV is widely estimated using anthropometric measurements (see Mirwald, Baxter-Jones, Bailey, & Beunen, 2002 for more details).

Additionally, it has been reported that anthropometry and performance dimensions alone can contribute to a maturity-selection bias, in which early-maturing players are over-selected (Carling, Le Gall, & Malina, 2012). Some professional soccer club confederations, such as the English Premier League, have invested in the development frameworks of athletes considering the influence of maturity status (Ford, et al., 2011). Overall, practitioners and coaches should establish realistic expectations for physical abilities of younger players, considering their biological characteristics rather than relying solely on chronological age-based standards (Deprez, et al., 2013).

Using maturity status in talent identification offers advantages but raises ethical concerns. By accounting for maturity, evaluations can differentiate players based on developmental stage rather than age alone, improving accuracy and reducing bias towards early maturers who may appear more physically capable. This approach supports creating developmentally appropriate training programmes, minimizing injury risks and setting realistic performance expectations. However, labelling players by maturity can lead to bias, where late-maturing athletes may be undervalued, limiting their development opportunities and impacting their self-esteem. To ensure fairness, talent identification must balance these practices to prevent exclusion, provide equal developmental resources, and avoid potential biases, supporting all athletes regardless of their maturity level.

Lower limbs strength

Likewise, we observed that lower limbs strength was also among the most evaluated parameters in the studies included in this review, investigated in 77 (40.5%) articles. Lower limbs strength can be easily estimated by measuring vertical jump height using validated tools such as smartphone applications (Cruvinel-Cabral, et al., 2018) and stride sensors (Santos, et al., 2021). The countermovement jump was the most used test of lower limbs power, present in 59 (76.6%) studies that evaluated the lower limbs strength of their subjects. Lower limbs strength is a crucial aspect of soccer performance as it involves the ability of the muscles in the lower body, particularly the legs, to generate force quickly and explosively. This power is vital for actions like sprinting, jumping, kicking, and changing direction rapidly, all of which are fundamental in soccer (Murtagh, et al., 2018). Evidences indicate that jumping ability can distinguish between elite and sub-elite youth soccer players and may be valuable for coaching staff during the athlete selection process (Comfort, et al., 2013). Therefore, soccer academy coaches should consider including sprint ability and lower limbs power as parameters in their talent identification and development programmes.

Aerobic capacity

Aerobic capacity is well-known for its importance in excellency in soccer and incorporating aerobic conditioning and endurance training into a soccer players' regimen is essential for success on the field. It has been reported that elite soccer players usually cover up to 12km during a competitive official match at an average intensity of around 70% of their maximal oxygen consumption (Stølen, Chamari, Castagna, & Wisløff, 2005). Aerobic training postpones fatigue onset; thus, coaches employ soccer fitness drills and activities related to developing aerobic fitness.

Aerobic fitness is paramount in soccer performance as it enables the players to sustain high-intensity efforts throughout a match. In matches that frequently extend beyond 90 minutes, players with high aerobic condition, depending on their playing position, demonstrate improved endurance that enables them to sustain peak performance, make critical decisions, and execute skills effectively, even in the final stages of the game (Deprez, et al., 2015). Moreover, a well-conditioned aerobic system facilitates rapid recovery between sprints, reducing the risk of fatigue-induced errors and injuries (Roe & Malone, 2016). Endurance capacity also enables players to cover more ground, contributing both offensively and defensively. Additionally, aerobic fitness provides adaptability to different styles of play, making it an indispensable factor of a successful soccer player. Moreover, it has been reported that aerobic fitness, a key factor for soccer performance, increases by age- and maturity-status-driven morphological changes (Armstrong & Welsman, 2019).

Out of the 68 studies included in this review, which assessed the aerobic performance of the participants, 46 (67.6%) used the Yo-Yo intermittent recovery test level 1. The test provides an estimate of an individual's maximal aerobic speed and his/her ability to recover from high-intensity efforts. It is a valuable tool for coaches and athletes to monitor and evaluate aerobic fitness, especially in sports where repeated bouts of high-intensity efforts are common.

Agility

Agility, also regarded as an essential skill in soccer, was largely investigated in 62 (32.6%) studies included in this review. Agility is recognized as a vital physical ability in competitive team sports, including soccer, as it empowers players to quickly change direction, evade opponents, and react swiftly to the dynamic demands of the game (Krolo, et al., 2020). In soccer, where decisions and sudden shifts in movements are widely common, agile players gain a technical advantage by outmaneuvering opponents and creating scoring opportunities. Whether executing precise dribbles, defending against attacking runs, or transitioning from offense to defense, agility is a crucial ability to maintain control and effectiveness considering the fast-paced and dynamic nature of soccer. Additionally, it has been demonstrated that neuromuscular training significantly improves agility performance of elite soccer players (Wojtys, Huston, Taylor, & Bastian, 1996), which is associated with lower incidence of injuries (Mijatovic, Krivokapic, Versic, Dimitric, & Zenic, 2022). Thus, agility stands as a cornerstone of a players' holistic skill set, enabling them to excel in the complex and multifaceted demands of high-level soccer.

Technical skills

Proficiency in technical skills, investigated in 32 (16.8%) studies included in this review, plays a pivotal role in optimal performance in the sport. Dribbling, the art of controlling the ball in motion, empowers players to navigate through intricate defensive formations, affording them a strategic advantage and enabling fluid offensive plays. Accurate passing, a cornerstone of effective teamwork, facilitates ball circulation, cohesive team dynamics, and the execution of strategic maneuvers. Juggling, while displaying a players' exceptional ball-controlling dexterity, refines their touch and spatial awareness, enhancing their versatility on the field. Shooting, the combination of precision, power, and technique, holds the potential to change the score of the game. Finally, heading, a specialized skill, endows players with a distinct advantage in aerial duels, both in attack and defense. Collectively, these technical skills serve as the foundational elements that not only distinguish elite players but also catalyze the orchestration of cohesive, dynamic, and tactically astute gameplay (Esposito & Raiola, 2020). In our review, we observed that dribbling, passing, touching, juggling, shooting, and heading skills were assessed in the majority of the studies. Mastery of these skills, as well as other factors such as teamwork, strategy, and mental toughness, can help players to succeed in the sport at all levels, from amateur to professional (Focan, Paraschiv, & Zamfir, 2018).

Tactical skills

In our scoping review, we found that tactical characteristics were assessed in 27 studies (14.2%). Among these, five studies employed the Tactical Skills Inventory for Sports (TACSIS), a self-assessment questionnaire, developed by Elferink-Gemser, Visscher, Richart, and Lemmink (2004). In team sports, tactical skills involve a player's ability to execute the appropriate action at the right moment and swiftly adjust to changes in the play and the movement of the ball (Elferink-Gemser, et al., 2004). These skills encompass key elements such as positioning and decision-making, understanding ball dynamics, awareness of other players, and adaptability in changing situations (Abarghoueinejad, et al., 2021). Tactical skills like behavior in one-on-one offensive and defensive situations, anticipation, decision-making, and game intelligence are critical for reaching elite performance in soccer (Roca, Williams & Ford, 2012). Therefore, coaches should consider including tactical skills tests in their talent identification programmes because such a comprehensive evaluation helps ensure that the selected players have the potential to perform well under pressure, contribute to team success, and develop into top-level athletes.

Psychological characteristics

Psychological skills were each assessed in 22 (11.6%) of the studies included in this scoping review. Sports psychology is a field within psychology that focuses on the scientific study of individuals and their behavior in the context of sports or physical activity. One of its key aims is to understand emotional stabilization, making the exploration of both positive and negative emotions its central area of interest (Martinent, Ledos, Ferrand, Campo, & Nicolas, 2015). In the realm of sports, emotions such as stress, pressure, tension, competition anxiety, nervousness, concern, and fright have garnered significant experimental interest. In sports psychology, these emotions are often classified as different forms of anxiety. They are a major focus of study, as they involve unpleasant sensations that can impact performance in either positive or negative ways, and are frequently debated and analyzed by psychologists (Burton & Naylor, 1997). Regarding the optimization of talent identification and development in sports, the importance of developing psychosocial characteristics in younger athletes was highlighted, noting that these traits may not yet be fully developed but could be crucial for future success (Till & Baker, 2020). Given the significant impact of emotions like anxiety on athletic performance, coaches should consider incorporating tests related to psychological characteristics into their talent identification programmes.

Motor coordination and motion-video analysis

Our scoping review also identified 15 studies (7.9%) that evaluated motor coordination and 17 studies (8.9%) that conducted motion tracking analysis using footage or global positioning system (GPS) tracking. Motor coordination skills play a crucial role in soccer, as they directly impact players' ability to perform various movements and techniques on the field (Archer, Drysdale, & Bradley, 2016). Players can improve their motor coordination skills through soccer participation as it enhances lower limb coordination and reduces motor lateralization. Additionally, utilizing foot motor performance measurements for talent identification in soccer could be advantageous for selecting less lateralized players from the beginning (Akpinar, 2022). The Körperkoordinationstest für Kinder prominently surfaced as the most frequently utilized evaluation instrument within the scope of our study, present in 10 studies. The specific components of the test may vary, but common elements often include tasks regarding balance, agility, spatial awareness, and fine motor skills. Results from this test can provide valuable insights into a child's physical development, motor proficiency, and potential areas for improvement (Novak, et al., 2017).

Likewise, motion tracking analysis in soccer involves using technology to capture and analyze movements of players and the ball during a match. This sophisticated technique provides valuable data that can be used for several purposes in soccer, including tactical analysis (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez, & Pino-Ortega, 2019) and performance improvement (Reinhardt, Schwesig, Lauenroth, Schulze, & Kurz, 2019). The majority of the studies included in this scoping review used game footage and GPS tracking for motion analysis in their investigations.

Small-sided games

Small-sided games were also evaluated as a variable related to talent identification and development in soccer, appearing in 14 (7.4%) of the articles included in this scoping review. Small-sided games refer to matches played on a smaller field with fewer players on each team compared to the traditional full-field matches. The number of players, field size, and rules can vary, but they typically involve three to five players per team. This training method is used to develop specific skills, improve fitness, and enhance tactical understanding. It has been reported that the tactical demands of small-sided games reflect those of 11-vs-11 games (Olthof, Frencken, & Lemmink, 2019). Small-sided games are played on reduced field areas with fewer players and modified rules, with the capability of replicating the movement requirements, physiological intensity, and technical demands of an actual match-play (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). It has been suggested that small-sided games play a significant role in developing technical skills and tactical awareness (Little, 2009). The popularity of small-sided games as a training modality in soccer is primarily due to their practicability, low cost, and overall similarity with competitive match-play. Coaches could benefit from these advantages in their pursuit of soccer talents. In addition, it is well known that soccer requires a range of skills that are specific to the sport, including technical, tactical, physical, and mental skills.

Strength of the upper body and flexibility

Strength of the upper body and flexibility were evaluated in 11 (5.8%) and 14 (7.4%) studies included in this review, respectively. Although soccer is primarily a sport that involves running, agility, and lower body strength, upper body strength is still important for several aspects of the game, including balance and stability, throw-ins, physical duels and prevention of injury due to falls (Sabag, et al., 2020). The medicine ball throw test was the most commonly used test to measure upper body power and strength. Its objective is to measure the maximum distance an individual can throw a medicine ball (usually weighing 2-5 kg) from a standing or sitting position. Similarly, flexibility is an important component of physical fitness for soccer players as it plays a crucial role in injury prevention, range of motion, agility, and overall athletic performance (Cejudo, et al., 2019). The sit-and-reach test was widely investigated to evaluate flexibility of soccer athletes in the studies included in this scoping review, mostly due to its practicability, efficiency, and reliability.

Other variables

In addition to the commonly assessed variables, this scoping review identified a range of other factors evaluated across a smaller number of studies, which may offer deeper insights into soccer talent development and performance. One such factor is time of match-play, which has been explored for its role in understanding how experience and exposure in game-play affect skill acquisition and performance consistency (Clemente, et al., 2021). Hormonal factors were another key area, reflecting an increased focus on how hormonal fluctuations, such as cortisol and testosterone levels, can impact training adaptation, recovery, and mental resilience (Baldari, et al., 2009). This emphasis on hormonal responses underscores their potential influence in predicting player readiness and long-term development (Eskandarifard, Nobari, Sogut, Clemente, & Figueiredo, 2022). Finally, this review highlights physiological factors as critical to a holistic approach, including cardiovascular capacity, muscle endurance, and metabolic efficiency (Nobari, et al., 2021; Waldron & Murphy, 2013). Together, these diverse factors highlight the importance of a multidimensional framework for assessing soccer talent, integrating physical, biological, and experiential elements to provide a comprehensive understanding of what contributes to a player's potential.

The inclusion of less studied variables like time of match-play, hormonal factors, and physiological factors enhances talent identification in soccer by addressing essential aspects of a player's development that traditional metrics may overlook. Time of play offers insights into endurance, resilience, and decision-making over extended periods, reflecting a player's capacity to maintain performance under fatigue, which is a key in high-stakes matches (Mohr, Krustrup, & Bangsbo, 2003). Hormonal factors provide valuable information on growth, recovery, and adaptation, helping to assess players' readiness for training and competition and identifying those who may be at risk of overtraining or injury due to rapid physical development (Baldari, et al., 2009). Additionally, examining physiological factors like heart rate variability and metabolic efficiency reveals how players manage energy during different intensities, which is crucial for sustaining high performance throughout matches (Nobari, et al., 2021). Together, these variables deliver a comprehensive view of a player's endurance, physical readiness, and adaptability, making talent identification more effective by considering long-term developmental and health aspects essential for reaching elite levels in soccer.

Limitations and future perspectives

A limitation of this literature review is that we included only studies in English from Pubmed, Web of Science, and Scopus databases. Thus, we may have overlooked other relevant studies published in other languages or from other databases. Additionally, we observed that most of the studies in this review addressed the talent identification and development process in male athletes. Given the findings of this scoping review, future research should expand the focus on underrepresented areas in talent identification and development in soccer. Specifically, there is a need for more studies involving female athletes to ensure that the processes and variables assessed are equally applicable across sexes. Additionally, the integration of more sophisticated and objective assessment tools, such as wearable technology and machine learning algorithms, could enhance the accuracy and predictive power of talent identification models. Future investigations should also explore the influence of psychological and social factors, which remain less examined, on the development and progression of young soccer players.

The methodological quality of the studies included in this review was generally robust, with cross-sectional studies meeting an average of 95% of the quality criteria, while longitudinal studies met an average of 81% based on the established appraisal tools. However, variability in study design, sample sizes, and the types of assessment tools used may impact the interpretation of findings, particularly concerning talent identification metrics. Most studies relied on field-based tests, which, while practical and cost-effective, may lack the precision of laboratory assessments for capturing detailed physiological or technical data. Additionally, the predominance of cross-sectional designs limits insights into the developmental trajectories of athletes, which are critical for understanding long-term talent progression. This methodological diversity introduces some inconsistency in data comparability, suggesting a need for standardized assessment protocols to ensure that findings are both reliable and generalizable across different contexts in soccer talent identification.

Our findings highlight the complex relationship between physical performance, technical-tactical skills, and maturity status in talent identification programmes in soccer. While the review highlights the frequent assessment of these factors, it also raises questions about the potential over-reliance on physical attributes at the expense of a more holistic evaluation. Moreover, the limited focus on psychological characteristics suggests a gap in current talent identification frameworks, potentially missing critical elements that contribute to long-term success in sports. Therefore, a more balanced and comprehensive assessment strategy is recommended, which equally values physical, technical, psychological, and maturity-related factors to ensure a more inclusive and effective talent identification process.

Additionally, the findings of this review reveal a significant emphasis on physical performance parameters, such as sprint speed, lower limb strength, and aerobic capacity, in talent identification programmes for youth soccer players. However, overreliance on physical assessments risks overlooking other critical attributes which contribute to, long-term player success. This approach may favor early maturing athletes who excel in physical tests, potentially leading to a maturity-selection bias and overlooking players who may develop these capacities later but possess strong technical, tactical, or psychological skills. Therefore, while physical capabilities are essential, a more balanced approach incorporating technical skills, decision-making abilities, and psychological resilience is crucial. This holistic approach could provide a more inclusive pathway for identifying talent, ensuring that players with diverse strengths, beyond physical performance, have the opportunity to progress and maximize their potential in the sport.

Finally, female athletes are underrepresented in talent identification research, with only 7.4% of studies including female participants. This gap limits the understanding of how physiological, psychological, and social factors uniquely impact talent in women's soccer. Female athletes experience different physical development timelines, with factors like hormonal fluctuations and muscle distribution influencing performance metrics differently than in males. Additionally, social and psychological motivators, such as a supportive environment, are crucial for sustained engagement in sports for females. Without dedicated research, talent identification programmes risk using biased evaluation criteria that may undervalue the strengths of female athletes, such as agility, endurance, or tactical insight. Addressing this research gap is essential for developing more inclusive talent identification frameworks that reflect the diverse capabilities of female players.

Our study provides a review of the current literature regarding the dimensions of the talent identification and development process in youth soccer, as well as the variables and tests used for these evaluations. From the studies reviewed, we concluded that sprint performance, maturity status, lower limbs power, anthropometric measures, aerobic capacity, and agility were the most evaluated variables in the articles available in literature. Furthermore, most of the tests used to evaluate these variables are affordable and practical. Researchers and practitioners in soccer talent identification should adopt a balanced, multidimensional approach that includes physical, technical, tactical, and psychological variables alongside maturity status to accurately assess player potential. Actionable recommendations include implementing assessments that go beyond physical performance, such as incorporating decision-making and game intelligence tests, which reflect real-game demands. Practitioners should be cautious of over-reliance on maturity-linked physical attributes to avoid bias towards early maturers, ensuring that late-developing players are provided equal opportunities and resources for development. To address the gaps identified in this review, future research should prioritize more comprehensive, longitudinal studies that assess both male and female athletes across a broader range of variables, including technical, tactical, and psychological factors alongside physical attributes.

References

Abarghoueinejad, M., Barreira, D., Dias, C., Guimarães, E., Baxter-Jones, A. D. G., & Maia, J. (2021). Body physique, body composition, physical performance, technical and tactical skills, psychological development, and club characteristics of young male Portuguese soccer players: The INEX study. *International Journal of Environmental Research and Public Health*, *18*(7). https://doi.org/10.3390/ijerph18073560

Akpinar, S. (2022). Participation of soccer training improves lower limb coordination and decreases motor lateralization. *BioMed Research International*, *2022*, Article ID 7525262. https://doi.org/10.1155/2022/7525262

Albaladejo-Saura, M., Vaquero-Cristóbal, R., González-Gálvez, N., & Esparza-Ros, F. (2021). Relationship between biological maturation, physical fitness, and kinanthropometric variables of young athletes: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *18*(1), 328. https://doi.org/10.3390/ijerph18010328

Archer, D.T., Drysdale, K., & Bradley, E.J. (2016). Differentiating technical skill and motor abilities in selected and non-selected 3-5 year old team-sports players. *Human Movement Science*, *47*, 81-87. https://doi.org/10.1016/j.humov.2016.02.001

Armstrong, N., & Welsman, J. (2019). Clarity and confusion in the development of youth aerobic fitness. *Frontiers in Physiology*, *10*(JUL), Article ID 979. https://doi.org/10.3389/fphys.2019.00979

Baker, J., Schorer, J., & Cobley, S. (2010). Relative age effects: An inevitable consequence of elite sport? *Sportwissenschaft*, *40*(1), 26-30. https://doi.org/10.1007/s12662-009-0095-2

Baldari, C., Di Luigi, L., Emerenziani, G.P., Gallotta, M.C., Sgró, P., & Guidetti, L. (2009). Is explosive performance influenced by androgen concentrations in young male soccer players? *British Journal of Sports Medicine*, *43*(3), 191-194. https://doi.org/10.1136/bjsm.2007.040386

Bastida-Castillo, A., Gómez-Carmona, C.D., De La Cruz Sánchez, E., & Pino-Ortega, J. (2019). Comparing accuracy between global positioning systems and ultra-wideband-based position tracking systems used for tactical analyses in soccer. *European Journal of Sport Science*, *19*(9), 1157-1165. https://doi.org/10.1080/17461391.2019.1584248

Bergkamp, T.L.G., Frencken, W.G.P., Niessen, A.S.M., Meijer, R.R., & den Hartigh, R.J.R. (2021). How soccer scouts identify talented players. *European Journal of Sport Science*. https://doi.org/10.1080/17461391.2021.1916081

Bergkamp, T.L.G., Niessen, A.S.M., den Hartigh, R.J.R., Frencken, W.G.P., & Meijer, R.R. (2019). Methodological issues in soccer talent identification research. *Sports Medicine*, *49*(9), 1317-1335. https://doi.org/10.1007/s40279-019-01113-w

Bidaurrazaga-Letona, I., Lekue, J.A., Amado, M., Santos-Concejero, J., & Gil, S.M. (2015). Identifying talented young soccer players: Conditional, anthropometrical and physiological characteristics as predictors of performance. *RICYDE: Revista Internacional de Ciencias Del Deporte*, *11*(39), 79-95. https://doi.org/10.5232/ricyde2015.03906

Bilgiç, M., & Işın, A. (2023). Embarking on a journey: A bibliometric analysis of the relative age effect in sport science. *German Journal of Exercise and Sport Research*, *53*(3), 325-332. https://doi.org/10.1007/s12662-021-00792-w

Bourke, A. (2003). The dream of being a professional soccer player. *Journal of Sport and Social Issues*, *27*(4), 399-419. https://doi.org/10.1177/0193732503255478

Burton, D., & Naylor, S. (1997). Is anxiety really facilitative? Reaction to the myth that cognitive anxiety always impairs sport performance. *Journal of Applied Sport Psychology*, *9*(2), 295-302. https://doi.org/10.1080/10413209708406488

Carling, C., Le Gall, F., & Malina, R.M. (2012). Body size, skeletal maturity, and functional characteristics of elite academy soccer players on entry between 1992 and 2003. *Journal of Sports Sciences*, *30*(15), 1683-1693. https://doi.org/10.1080/02640414.2011.637950

Cejudo, A., Robles-Palazón, F.J., Ayala, F., De Ste Croix, M., Ortega-Toro, E., Santonja-Medina, F., & De Baranda, P.S. (2019). Age-related differences in flexibility in soccer players 8-19 years old. *PeerJ*, *7*(1), e6236. https://doi.org/10.7717/peerj.6236

Clemente, F.M., Clark, C.C.T., Leão, C., Silva, A.F., Lima, R., Sarmento, H., Figueiredo, A.J., Rosemann, T., & Knechtle, B. (2021). Exploring relationships between anthropometry, body composition, maturation, and selection for competition: A study in youth soccer players. *Frontiers in Physiology*, *12*, 651735. https://doi.org/10.3389/fphys.2021.651735

Comfort, P., Stewart, A., Bloom, L., & Clarkson, B. (2013). A comparison of performance characteristics in elite and sub-elite youth soccer players. *Journal of Strength and Conditioning Research*, *30*(6), 1534-1539. https://doi.org/10.1519/JSC.0000000000001243

Comfort, P., Stewart, A., Bloom, L., & Clarkson, B. (2014). Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *Journal of Strength and Conditioning Research*, *28*(1), 173-177. https://doi.org/10.1519/JSC.0b013e318291b8c7

Craig, T.P., & Swinton, P. (2021). Anthropometric and physical performance profiling does not predict professional contracts awarded in an elite Scottish soccer academy over a 10-year period. *European Journal of Sport Science*, *21*(8), 1101-1110. https://doi.org/10.1080/17461391.2020.1808079

Cruvinel-Cabral, R.M., Oliveira-Silva, I., Medeiros, A.R., Claudino, J.G., Jiménez-reyes, P., & Boullosa, D.A. (2018). The validity and reliability of the "My Jump App" for measuring jump height of the elderly. *PeerJ*, *6*(1), e5804. https://doi.org/10.7717/peerj.5804

Deprez, D.N., Coutts, A.J., Fransen, J., Deconinck, F., Lenoir, M., Vaeyens, R., & Philippaerts, R. (2013). Relative age, biological maturation and anaerobic characteristics in elite youth soccer players. *International Journal of Sports Medicine*, *34*(10), 897-903. https://doi.org/10.1055/s-0032-1333262

Deprez, D.N., Fransen, J., Boone, J., Lenoir, M., Philippaerts, R., & Vaeyens, R. (2015). Characteristics of high-level youth soccer players: Variation by playing position. *Journal of Sports Sciences*, *33*(3), 243-254. https://doi.org/10.1080/02640414.2014.934707

Elferink-Gemser, M.T., Visscher, C., Richart, H., & Lemmink, K.A.P.M. (2004). Development of the tactical skills inventory for sports. *Perceptual and Motor Skills*, *99*(7), 883. https://doi.org/10.2466/pms.99.7.883-895

Eskandarifard, E., Nobari, H., Sogut, M., Clemente, F.M., & Figueiredo, A.J. (2022). Exploring interactions between maturity status and playing time with fluctuations in physical fitness and hormonal markers in youth soccer players. *Scientific Reports*, *12*(1), Article No. 4463. https://doi.org/10.1038/s41598-022-08567-5

Esposito, G., & Raiola, G. (2020). Monitoring the performance and technique consolidation in youth football players. *Trends in Sport Sciences*, *27*(2), 93-100. https://doi.org/10.23829/TSS.2020.27.2-6

Fernández-Rio, J., & Méndez-Giménez, A. (2014). Talent detection and development in soccer: A review. *Journal of Sport and Health Research*, *6*(1), 7–18.

Focan, G., Paraschiv, C., & Zamfir, C.M. (2018). The identification of talent in soccer—A brief review. *Revista Romaneasca Pentru Educatie Multidimensionala*, *10*(4), 282-293. https://doi.org/10.18662/rrem/88

Ford, P.R., Bordonau, J.L.D., Bonanno, D., Tavares, J., Groenendijk, C., Fink, C., Gualtieri, D., Gregson, W., Varley, M.C., Weston, M., Lolli, L., Platt, D., & Di Salvo, V. (2020). A survey of talent identification and development processes in the youth academies of professional soccer clubs from around the world. *Journal of Sports Sciences*, *38*(11-12), 1269-1278. https://doi.org/10.1080/02640414.2020.1752440

Ford, P.R., de Ste Croix, M., Lloyd, R., Meyers, R., Moosavi, M., Oliver, J., Till, K., & Williams, C. (2011). The Long-Term Athlete Development model: Physiological evidence and application. *Journal of Sports Sciences*, *29*(4), 389-402. https://doi.org/10.1080/02640414.2010.536849

Helsen, W.F., Baker, J., Michiels, S., Schorer, J., van Winckel, J., & Williams, A.M. (2012). The relative age effect in European professional soccer: Did ten years of research make any difference? *Journal of Sports Sciences*, *30*(15), 1665-1671. https://doi.org/10.1080/02640414.2012.721929

Hill-Haas, S., Dawson, B., Impellizzeri, F., & Coutts, A. (2011). Physiology of small-sided games training in football. *Journal of Sports Medicine*, *41*(3), 199-220. https://doi.org/10.2165/11539740-000000000-00000

Höner, O., Votteler, A., Schmid, M., Schultz, F., & Roth, K. (2015). Psychometric properties of the motor diagnostics in the German football talent identification and development programme. *Journal of Sports Sciences*, *33*(2), 145-159. https://doi.org/10.1080/02640414.2014.928416

Hunter, A.H., Smith, N.M.A., Camata, T.V., Crowther, M.S., Mather, A., Souza, N.M., Ramos-Silva, L.F., Pazetto, N.F., Moura, F.A., & Wilson, R.S. (2022). Age- and size-corrected kicking speed and accuracy in elite junior soccer players. *Science and Medicine in Football*, *6*(1), 29-39. https://doi.org/10.1080/24733938.2021.1899274

Krolo, A., Gilic, B., Foretic, N., Pojskic, H., Hammami, R., Spasic, M., Uljevic, O., Versic, S., & Sekulic, D. (2020). Agility testing in youth football (soccer)players; evaluating reliability, validity, and correlates of newly developed testing protocols. *International Journal of Environmental Research and Public Health*, *17*(1), 294. https://doi.org/10.3390/ijerph17010294

Larkin, P., & O'Connor, D. (2017). Talent identification and recruitment in youth soccer: Recruiter's perceptions of the key attributes for player recruitment. *PLoS ONE*, *12*(4), e0175716. https://doi.org/10.1371/journal.pone.0175716

Little, T. (2009). Optimizing the use of soccer drills for physiological development. *Strength and Conditioning Journal*, *31*(3), 67-74. https://doi.org/10.1519/SSC.0b013e3181a5910d

Malina, R.M., Coelho-e-Silva, M.J., Figueiredo, A.J., Philippaerts, R.M., Hirose, N., Peña Reyes, M.E., Gilli, G., Benso, A., Vaeyens, R., Deprez, D., Guglielmo, L.F., & Buranarugsa, R. (2018). Tanner–Whitehouse skeletal ages in male youth soccer players: TW2 or TW3? *Sports Medicine*, *48*(4), 991-1008. https://doi.org/10.1007/s40279-017-0799-7

Malina, R.M., Eisenmann, J.C., Cumming, S.P., Ribeiro, B., & Aroso, J. (2004). Maturity-associated variation in the growth and functional capacities of youth football (soccer) players 13-15 years. *European Journal of Applied Physiology*, *91*(5-6), 555-562. https://doi.org/10.1007/s00421-003-0995-z

Martinent, G., Ledos, S., Ferrand, C., Campo, M., & Nicolas, M. (2015). Athletes' regulation of emotions experienced during competition: A naturalistic video-assisted study. *Sport, Exercise, and Performance Psychology*, *4*(3), 188-205. https://doi.org/10.1037/spy0000037

Mijatovic, D., Krivokapic, D., Versic, S., Dimitric, G., & Zenic, N. (2022). Change of direction speed and reactive agility in prediction of injury in football: Prospective analysis over one half-season. *Healthcare (Switzerland)*, *10*(3), 440. https://doi.org/10.3390/healthcare10030440

Mirwald, R.L., Baxter-Jones, A.D.G., Bailey, D.A., & Beunen, G.P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise*, *34*(4), 689-694. https://doi.org/10.1097/00005768-200204000-00020

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences*, *21*(7), 519-528. https://doi.org/10.1080/0264041031000071182

Munn, Z., Moola, S., Lisy, K., Riitano, D., & Tufanaru, C. (2015). Methodological guidance for systematic reviews of observational epidemiological studies reporting prevalence and cumulative incidence data. *International Journal of Evidence-Based Healthcare*, *13*(3), 147-153. https://doi.org/10.1097/XEB.0000000000000054

Murtagh, C.F., Brownlee, T.E., O'Boyle, A., Morgans, R., Drust, B., & Erskine, R.M. (2018). Importance of speed and power in elite youth soccer depends on maturation status. *Journal of Strength and Conditioning Research*, *32*(2), 297-303. https://doi.org/10.1519/JSC.0000000000002367

Nobari, H., Silva, A.F., Clemente, F.M., Siahkouhian, M., García-Gordillo, M.Á., Adsuar, J.C., & Pérez-Gómez, J. (2021). Analysis of fitness status variations of under-16 soccer players over a season and their relationships with maturational status and training load. *Frontiers in Physiology*, *11*, 597697. https://doi.org/10.3389/fphys.2020.597697

Novak, A.R., Bennett, K.J.M., Beavan, A., Pion, J., Spiteri, T., Fransen, J., & Lenoir, M. (2017). The applicability of a short form of the Körperkoordinationstest für Kinder for measuring motor competence in children aged 6 to 11 years. *Journal of Motor Learning and Development*, *5*(2), 227-239. https://doi.org/10.1123/jmld.2016-0028

Olthof, S.B.H., Frencken, W.G.P., & Lemmink, K.A.P.M. (2019). A match-derived relative pitch area facilitates the tactical representativeness of small-sided games for the official soccer match. *Journal of Strength and Conditioning Research*, *33*(2), 523-530. https://doi.org/10.1519/JSC.0000000000002978

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan—A web and mobile app for systematic reviews. *Systematic Reviews*, *5*, 210. https://doi.org/10.1186/s13643-016-0384-4

Patel, R., Nevill, A., Cloak, R., Smith, T., & Wyon, M. (2019). Relative age, maturation, anthropometry and physical performance characteristics of players within an elite youth football academy. *International Journal of Sports Science and Coaching*, *14*(6), 714-725. https://doi.org/10.1177/1747954119879348

Philippaerts, R.M., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., Bourgois, J., Vrijens, J., Beunen, G., & Malina, R.M. (2006). The relationship between peak height velocity and physical performance in youth soccer players. *Journal of Sports Sciences*, *24*(3), 221-230. https://doi.org/10.1080/02640410500189371

Pino-Ortega, J., Rojas-Valverde, D., Gómez-Carmona, C.D., & Rico-González, M. (2021). Training design, performance analysis and talent identification—A systematic review about the most relevant variables through the principal component analysis in soccer, basketball and rugby. *International Journal of Environmental Research and Public Health*, *18*(5), 1-18. https://doi.org/10.3390/ijerph18052642

Rampinini, E., Coutts, A.J., Castagna, C., Sassi, R., & Impellizzeri, F.M. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine*, *28*(12), 1018-1024. https://doi.org/10.1055/s-2007-965158

Reinhardt, L., Schwesig, R., Lauenroth, A., Schulze, S., & Kurz, E. (2019). Enhanced sprint performance analysis in soccer: New insights from a GPS-based tracking system. *PLoS ONE*, *14*(5), e0217782. https://doi.org/10.1371/journal.pone.0217782

Roca, A., Williams, A.M., & Ford, P.R. (2012). Developmental activities and the acquisition of superior anticipation and decision making in soccer players. *Journal of Sports Sciences*, *30*(15), 1643-1652. https://doi.org/10.1080/02640414.2012.701761

Roe, M., & Malone, S. (2016). Yo-Yo Intermittent Recovery Test performance in subelite Gaelic football players from under thirteen to senior age groups. *Journal of Strength and Conditioning Research*, *30*(11), 3187-3193. https://doi.org/10.1519/JSC.0000000000001417

Sabag, A., Lovell, R., Walsh, N.P., Grantham, N., Lacome, M., & Buchheit, M. (2020). Upper-body resistance training following soccer match play: Compatible, complementary, or contraindicated? *International Journal of Sports Physiology and Performance*, *16*(2), 165-175. https://doi.org/10.1123/ijspp.2020-0762

Santos, M.A.P. dos, Cabido, C.E.T., Silvino, V.O., Mesquita, A.R. de, Nascimento, F.L.S. do, Neto, S.L. de A., Goulart, K.N. de, Szmuchrowski, L.A., Pena, B.C., Albuquerque-Neto, S.L. de, Goulart, K.N. de, Szmuchrowski, L.A., & Pena, B.C. (2021). Validity of the Polar V800 to measure vertical jump performance in taekwondo athletes. *IDO MOVEMENT FOR CULTURE. Journal of Martial Arts Anthropology*, *21*(1), 12-18. https://doi.org/10.14589/ido.21.1.3

Sarmento, H., Anguera, M.T., Pereira, A., & Araújo, D. (2018). Talent identification and development in male football: A systematic review. *Sports Medicine*, *48*(4), 907-931. https://doi.org/10.1007/s40279-017-0851-7

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer: An update. *Sports Medicine*, *35*(6), 501-536. https://doi.org/10.2165/00007256-200535060-00004

Till, K., & Baker, J. (2020). Challenges and [possible] solutions to optimizing talent identification and development in sport. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.00664

Tricco, A.C., Lillie, E., Zarin, W., O'Brien, K.K., Colquhoun, H., Levac, D., Moher, D., Peters, M.D.J., Horsley, T., & Weeks, L. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*, *169*(7), 467-473. https://doi.org/10.7326/M18-0850

Vaeyens, R., Güllich, A., Warr, C.R., & Philippaerts, R. (2009). Talent identification and promotion programmes of Olympic athletes. *Journal of Sports Sciences*, *27*(13), 1367-1380. https://doi.org/10.1080/02640410903110974

Waldron, M., & Murphy, A. (2013). A comparison of physical abilities and match performance characteristics among elite and subelite under-14 soccer players. *Pediatric Exercise Science*, *25*(3), 423-434. https://doi.org/10.1123/pes.25.3.423

Wells, G., Shea, B., O'Connell, D., & Peterson, J. (2000). *The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses*. Ottawa, ON: Ottawa Hospital Research Institute. http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp

Williams, A.M. (2020). Talent identification and development in soccer: An update and contemporary perspectives. *Journal of Sports Sciences*, *38*(11-12), 1197-1198. https://doi.org/10.1080/02640414.2020.1773075

Williams, A.M., Ford, P.R., & Drust, B. (2020). Talent identification and development in soccer since the millennium. *Journal of Sports Sciences*, *38*(11-12), 1199-1210. https://doi.org/10.1080/02640414.2020.1766647

Williams, A.M., & Reilly, T. (2000). Talent identification and development in soccer. *Journal od Sports Sciences*, *18*(9), 657-667.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, *38*(3), 285-288. https://doi.org/10.1136/bjsm.2002.002071

Wojtys, E.M., Huston, L.J., Taylor, P.D., & Bastian, S.D. (1996). Neuromuscular adaptations in isokinetic, isotonic, and agility training programs. *American Journal of Sports Medicine*, *24*(2), 187-192. https://doi.org/10.1177/036354659602400212

Zago, M., Piovan, A.G., Annoni, I., Ciprandi, D., Iaia, F.M., & Sforza, C. (2016). Dribbling determinants in sub-elite youth soccer players. *Journal of Sports Sciences*, *34*(5), 411-419. https://doi.org/10.1080/02640414.2015.1057210

Submitted: January 23, 2024
Accepted: October 31, 2024
Published Online First: December 11, 2024

Correspondence to:
Valmir Oliveira Silvino
Department of Biophysics and Physiology, Federal University of Piauí
Teresina, Piauí, Brazil
Phone number: +55 86 3215-5696
E-mail address: valmirsilvino@live.com

Abbreviations

GPS, global positioning system; JBI, Joanna Briggs Institute; PHV, peak height velocity; PRISMA-ScR, Preferred Reporting Items for Systematic Review and Meta-Analyses Extension for Scoping Reviews; RAE, relative age effect.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgments

The authors would like to thank Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (FAPEMA BD-02488/21) for supporting this study.

SEARCH STRATEGY OF EACH DATABASE

Date of search: 19 september 2023

Databases:
Web of Science
PubMed
Scopus

Review question: What are the variables assessed in talent identification and development in soccer?
P (participants) (e.g., student, adolescent, child, young),
I (intervention) (e.g., program, intervention)
C (comparators) (e.g., football, soccer, "sport context")
O (outcomes) (e.g., identification, detection, selection, development).

PUBMED (N = 201)

Search:

(((((talent * OR "high ability" OR "above average")) AND (("football" OR "soccer"))) AND ((detection OR selection OR identification OR development))) AND ((program OR intervention OR test guideline))) AND ((student OR child * OR adolescent * OR young OR youth))

("aptitude"[MeSH Terms] OR "aptitude"[All Fields] OR "talent"[All Fields] OR "talents"[All Fields] OR "talented"[All Fields] OR "high ability"[All Fields] OR "above average"[All Fields]) AND ("football"[All Fields] OR "soccer"[All Fields]) AND ("detect"[All Fields] OR "detectabilities"[All Fields] OR "detectability"[All Fields] OR "detectable"[All Fields] OR "detectables"[All Fields] OR "detectably"[All Fields] OR "detected"[All Fields] OR "detectible"[All Fields] OR "detecting"[All Fields] OR "detection"[All Fields] OR "detections"[All Fields] OR "detects"[All Fields] OR ("select"[All Fields] OR "selectability"[All Fields] OR "selectable"[All Fields] OR "selected"[All Fields] OR "selecting"[All Fields] OR "selection s"[All Fields] OR "selection, genetic"[MeSH Terms] OR ("selection"[All Fields] AND "genetic"[All Fields]) OR "genetic selection"[All Fields] OR "selection"[All Fields] OR "selectional"[All Fields] OR "selections"[All Fields] OR "selective"[All Fields] OR "selectively"[All Fields] OR "selectives"[All Fields] OR "selectivities"[All Fields] OR "selectivity"[All Fields] OR "selects"[All Fields]) OR ("identifed"[All Fields] OR "identification, psychological"[MeSH Terms] OR ("identification"[All Fields] AND "psychological"[All Fields]) OR "psychological identification"[All Fields] OR "identification"[All Fields] OR "identifications"[All Fields]) OR ("develop"[All Fields] OR "develope"[All Fields] OR "developed"[All Fields] OR "developer"[All Fields] OR "developer s"[All Fields] OR "developers"[All Fields] OR "developing"[All Fields] OR "developments"[All Fields] OR "develops"[All Fields] OR "growth and development"[MeSH Subheading] OR ("growth"[All Fields] AND "development"[All Fields]) OR "growth and development"[All Fields] OR "development"[All Fields])) AND ("program"[All Fields] OR "program s"[All Fields] OR "programe"[All Fields] OR "programed"[All Fields] OR "programes"[All Fields] OR "programing"[All Fields] OR "programmability"[All Fields] OR "programmable"[All Fields] OR "programmably"[All Fields] OR "programme"[All Fields] OR "programme s"[All Fields] OR "programmed"[All Fields] OR "programmer"[All Fields] OR "programmer s"[All Fields] OR "programmers"[All Fields] OR "programmes"[All Fields] OR "programming"[All Fields] OR "programmings"[All Fields] OR "programs"[All Fields] OR ("intervention s"[All Fields] OR "interventions"[All Fields] OR "interventive"[All Fields] OR "methods"[MeSH Terms] OR "methods"[All Fields] OR "intervention"[All Fields] OR "interventional"[All Fields]) OR (("research design"[MeSH Terms] OR ("research"[All Fields] AND "design"[All Fields]) OR "research design"[All Fields] OR "test"[All Fields]) AND ("guideline"[Publication Type] OR "guidelines as topic"[MeSH Terms] OR "guideline"[All Fields]))) AND ("student s"[All Fields] OR "students"[MeSH Terms] OR "students"[All Fields] OR "student"[All Fields] OR "students s"[All Fields] OR ("child"[MeSH Terms] OR "child"[All Fields] OR "children"[All Fields] OR "child s"[All Fields] OR "children s"[All Fields] OR "childrens"[All Fields] OR "childs"[All Fields]) OR ("adolescences"[All Fields] OR "adolescency"[All Fields] OR "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "adolescence"[All Fields] OR "adolescents"[All Fields] OR "adolescent s"[All Fields]) OR ("young"[All Fields] OR "youngs"[All Fields]) OR ("adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "youth"[All Fields] OR "youths"[All Fields] OR "youth s"[All Fields]))

WEB OF SCIENCE (N = 235)

Search:

(talent OR "high ability" OR "above average") AND (football OR soccer detection OR selection OR identification OR development) AND (program OR intervention OR "test guideline") AND (student OR child OR adolescent OR young OR youth)

Scopus (N = 338)

Search:

(talent OR "high ability" OR "above average") AND (football OR soccer detection OR selection OR identification OR development) AND (program OR intervention OR "test guideline") AND (student OR child OR adolescent OR young OR youth)

Methods

The scoping review was performed in three databases (PubMed, Web of Science and Science-Direct) in September 2023 by two authors (VOS and CPF). The search strategy was performed following the Preferred Report Items for Systematic Reviews and Guidelines for the meta-analyses (PRISMA) [29], including the PICO strategy: P (participants) (e.g., student, adolescent, Child, young); I (Intervention) (program, Intervention); C (comparators) (e.g., football, soccer, "sport context"); O (Outcomes) (e.g., Identification, Detection, Selection, Development).

Supplementary Table 1. *Search strategy of each database*

Database	Search Strategy
PubMed	(((((talent * OR "high ability" OR "above average")) AND (("football" OR "soccer"))) AND ((detection OR selection OR identification OR development))) AND ((program OR intervention OR test guideline))) AND ((student OR child * OR adolescent * OR young OR youth))
Scopus	(talent OR "high ability" OR "above average") AND (football OR soccer detection OR selection OR identification OR development) AND (program OR intervention OR "test guideline") AND (student OR child OR adolescent OR young OR youth)
Web of Science	

DIFFERENCES IN MECHANICAL EFFICIENCY BETWEEN FEMALE AND MALE FOOTBALL PLAYERS DURING OFFICIAL MATCHES

Eider Barba[1,2], David Casamichana[1], Ane Iztueta[1], and Julen Castellano[2]

[1]Real Sociedad Institute, Real Sociedad de Fútbol S.A.D., Donostia-San Sebastián, Spain
[2]Research Group GIKAFIT, Department of Physical Education and Sport, Faculty of Education and Sport, University of the Basque Country (UPV/EHU), Vitoria-Gasteiz, Spain

Original scientific paper
DOI 10.26582/k.56.2.11

Abstract:

This study aimed to compare the values of external load measures and mechanical efficiency between male and female soccer players considering the match periods. A male professional soccer team (n=19) and a female professional soccer team (n=16) were monitored in official matches by Global Positioning System (GPS) devices (male 137 and female 144 observations). The external load variables studied were distance covered per minute (DCmin in $m \cdot min^{-1}$), player load per minute (PL in $AU \cdot min^{-1}$) and the mechanical efficiency obtained through the relationship of PL and DC (PLm in $AU \cdot m^{-1}$) over 90 minutes of official match divided into six periods of 15 minutes each. The results show that in all the periods studied, DCmin and PLmin for male soccer players were higher than for female players (ES: high and moderate for DCmin and PLmin, respectively; $p<.01$). However, there was no difference in mechanical efficiency between both genders. There was a decrease ($p<.01$) in PLmin and DCmin in the last periods of the match (0-15 > 15-30 = 30-45 = 45-60 > 60-75 = 75-90), as well as a decrease ($p<.01$) in PLm (0-15>30-45=60-75=75-90, 15-30>75-90 & 45-60>60-75=75-90 for male; and, 0-15>30-45=60-75=75-90, for female**)**. The decrease in values of PLmin and DCmin were not homogeneous, so the decoupling of these values in both genders as the match progresses could be induced by fatigue. Therefore, the findings could have a practical application: coaches and sports scientists could use the mechanical efficiency indicator to detect fatigue and then apply intervention strategies to improve performance or plan recovery.

Key words: *external load, GPS, soccer, team sport, gender*

Introduction

Soccer is a constantly evolving sport, whose physical demands include high-speed intermittent actions, accelerations and decelerations, turns, jumps, and shootings (Barnes, Archer, Hogg, Bush, & Bradley, 2014). All the actions carried out (external load) impact the player's organism (internal load), generating changes in player's system. For professionals in this sport, managing workloads to optimise athletes' performance is of great interest (Akubat, Patel, Barrett, & Abt, 2012; Akubat, Barrett, & Abt, 2014; Gabbett, et al., 2017). In recent years, proposals have been made to implement different technologies to analyse the demands of the sport. Among them, the Global Positioning System (GPS) is one of the most widespread systems in soccer (Dobson & Keogh, 2007). More recently, the implementation of micro-technology in GPS devices has been carried out, which makes it possible to go deeper into the analysis of the holistic profile of each player (Theodoropoulos, Bettle, & Kosy, 2020).

Since Boyd, Ball, and Aughey (2011) proposed this metric, PlayerLoad (PL), it has been used in many collective sports with different purposes (Gómez-Carmona, Bastida-Castillo, Ibáñez, & Pino-Ortega, 2020). The PL is an external load variable that presents good reliability and validity (Barrett, Midgley, & Lovell, 2014) and is obtained using inertial sensors (triaxial accelerometers with a high sampling frequency, e.g., 100 Hz), being the sum of the accelerations that occur in the three planes of body movement (Boyd, Ball, & Aughey, 2011; Cummins, Orr, O'Connor, & West, 2013). However, there is no consensus in the scientific literature regarding the formula used to calculate this variable (Bredt, Chagas, Peixoto, Menzel, & Andrade, 2020).

As indicated by Lacome, Simpson, and Buchheit in their study (2018), to understand the fatigue, performance, or injury risk of each player, it is valuable to analyze the variables in an integrated manner, as this provides more information than analyzing the variables separately. The response of the PL has shown a direct relationship with external load variables like distance covered (DC; Barrett, et al., 2016; Polglaze, Dawson, Hiscock, & Peeling, 2015) or metabolic power (MP; Reche-Soto, et al., 2019) and internal load variable like heart rate (McLaren, et al., 2018). Several studies applied to team sports have been interested in the detection of neuromuscular fatigue through the integration between locomotor-derived variables (e.g., DC) and accelerometer-based variables (e.g., PL) (McLaren, et al., 2018; Rowell, Aughey, Clubb, & Cormack, 2018). Thus, we understand mechanical efficiency as the lowest neuromuscular cost required in response to an external load (Buchheit, Gray, & Morin, 2015). Thus, the proposal arises to calculate mechanical efficiency by integrating the division of two known external load variables: PL, represented in arbitrary units (AU), and the DC in meters (Barrett, et al., 2016), giving rise to the variable PL per meter (PLm in $AU{\cdot}m^{-1}$).

Previous studies have analysed the PLm during a match divided into 15-minute periods, noting that as the match progressed, PLm increased, relating this increase to a lower mechanical efficiency (Barrett, et al., 2016). $AU{\cdot}m^{-1}$ has also been analyzed in training sessions over one week, revealing that a relatively high preceding weekly training load leads to an increase in $AU{\cdot}m^{-1}$ during a standardized SSG (Rowell, et al., 2018). Studies conclude that an increase in $AU{\cdot}m^{-1}$ reflects a fatigue-induced change in movement strategy.

It should be noted that female soccer has been booming in the last decade (Martínez-Lagunas, Niessen, & Hartmann, 2014). Even so, publications in this field are scarcer than in male soccer; the same is true for publications using GPS in this area (Cummins, et al., 2013; Rago, et al., 2020). As far as the authors of this study are aware, very few studies have analyzed PL in female soccer (Ramos, et al., 2019; Strauss, Sparks, & Pienaar, 2019), and none have established differences in terms of mechanical efficiency during soccer matches among players of different genders. These studies used PL in terms of intensity (e.g., PL divided by minutes of practice). The main findings show that $PL{\cdot}min^{-1}$ decreases in the match's second half and that midfielders have higher $PL{\cdot}min^{-1}$ values than defenders and forwards (Strauss, et al., 2019). On the other hand, Ramos et al. (2019) showed that senior players have higher $PL{\cdot}min^{-1}$ values in matches than U17 players. However, this concept of intensity could not be entirely representative of fatigue because it depends on the distance the athlete runs, which, although it may have an indirect relationship with fatigue (e.g., she runs less because she cannot keep up with other moments of the match), it could have to do with situational variables implicit in the match such as score, weather, substitutions..., which are known to condition physical performance (Carling, 2013).

For the reasoning previously stated, this study will compare the external load and mechanical efficiency during 15-minute periods between male and female soccer players. As a practical application, the description of the fatigue's evolution during the match can verify if, with the application of a suitable training process, we can make the efficiency deteriorate in a smaller amount and then apply intervention strategies to improve performance or plan recovery.

Materials and methods

Participants

In this study, 35 players were recruited from two different teams of the same professional Spanish club: the professional female team (n=16; age: 24.2±2.8 years; stature: 165.4±5.2 cm; body mass: 58.6±5.3 kg) and the professional male team (n=19; age: 21.3±1.6 years; stature: 171.6±41.6 cm; body mass: 72.2±6.8 kg). Data arose as a condition of the players' employment whereby they were assessed daily; thus, no authorization was required from an institutional ethics committee (Winter & Maughan, 2009). Nevertheless, this study conformed to the Declaration of Helsinki, and players provided informed consent before participating.

Measures

Three external load variables have been measured, two relative to intensity, DC per min (DCmin, in $m{\cdot}min^{-1}$) and PL per min (PLmin, in $AU{\cdot}min^{-1}$), and one mechanical efficiency indicator, obtained by dividing $PL{\cdot}min^{-1}$ and $DC{\cdot}min^{-1}$ (PLm, in $AU{\cdot}m^{-1}$). Previous studies have shown that PL is an external load indicator that presents a high inter- and intra-device reliability (Boyd, et al., 2011) and that it has been shown to be valid in the monitoring of the training and match-play load in soccer (Casamichana, Castellano, Calleja-Gonzalez, Roman, & Castagna, 2013).

Procedures

The study was conducted in the 2019-20 competitive season. The external load was collected using GPS devices (Vector S7 by Catapult). The number of satellites used to infer GPS signal quality, horizontal dilution of precision and the average of the Navigation Satellite System (GNSS) quality were for the F: 11.9±0.2 satellites, 0.8±0.1 and 67.9±4.3% and for the M: 12.0±0.8 satellites, 0.9±0.2 and 67.3±4.7%, respectively. Players wore a GPS device from the beginning until the end of the match. The GPS device was fitted to each player's upper back (e.g., between the shoulder blades) using an adjustable neoprene harness. After each game, the data was extracted to a computer and analyzed using Catapult OpenField v2.4. A total of 281 individual GPS files from match data were studied, with this distribution per team: 144 female and 137 male GPS files. Only data adopted from the full 90 minutes of a match were considered, so data from players who had not completed the entire match were excluded. The dependent variables studied were the three measures of external load, DCmin ($m \cdot min^{-1}$), PLmin ($AU \cdot min^{-1}$), and PLm ($AU \cdot m^{-1}$), while the independent variables were the different genders (male and female) and the six periods of the match (0-15, 15-30, 30-45, 45-70, 60-75, and 75-90 min).

Statistical analyses

For the comparison of the three variables (DCmin, PLmin, and PLm) intra-team or gender, during the six periods of 15 minutes, the analysis of variance (ANOVA) was used. While the analysis of the three dependent variables (DCmin, PLmin, and PLm) during the different time periods between genders was carried out by means of the Student's t-test. The descriptive statistics were calculated and expressed as mean and standard deviations (M±SD). All analyses were carried out using Excel and JASP statistical analysis software version 0.9.2 (University of Amsterdam, https://jasp-stats.org/). For the comparison between genders and match periods, the effect size (ES) was used, establishing the difference magnitudes as follows (Batterham & Hopkins, 2006): trivial (<0.2), low (>0.2-0.6), moderate (>0.6-1.2), high (>1.2-2.0) and very high (>2.0). The level of significance was set at $p<.01$.

Results

Table 1 and Figure 1 shows the DCmin by each gender team in each match period. In the period 0-15, DCmin values were higher than in the other periods in both teams (ES: 0.43-1.56). The lowest values were in the periods 60-75 and 75-90, with a significant difference from the other periods in both teams (ES: 0.40-1.56). On the other hand, in the 15-30 period of the female team, the DCmin was significantly greater than in the 30-45 period (ES: 0.73). Finally, if we compare the two teams in each period, there was a significant difference in all periods (ES: 0.71-1.56), with the values for the male team being higher than for the female team.

Table 2 and Figure 2 shows the PLmin of each team, divided into six match periods. In this variable, significantly higher values were also achieved in the first period with respect to the other periods, in both the male and female teams (ES: 0.46-1.42). The lowest PLmin occurred in the 60-75 and 75-90 periods, with a significant difference from the other periods in both teams (ES: 0.37-1.42). On the other hand, in the 15-30 period for the female team the workload was significantly higher than in the 30-45 (ES: 0.62) and 45-60 periods (ES: 0.38). Finally, if we compare the two teams in each period, there was a significant difference in all periods (ES: 0.51-1.07), with the values for the male team being higher than for the female team.

Finally, Table 3 and Figure 3 shows the PLm of each team in each match period. In the 0-15 period, in both the female and male teams, the PLm was significantly higher than in the 30-45, 60-75, and 75-90 periods (ES: 0.35-0.56). On the other hand, for the male team, significantly higher PLm was achieved in the 15-30 and 45-60 periods compared to 75-90 (ES: 0.40-0.53). It can also be seen that in

Table 1. Distance covered per minute (DCmin, in $m \cdot min^{-1}$) in each of the match periods in the female and male teams.

Gender	0-15	15-30	30-45	45-60	60-75	75-90	F(p)
Male	$120.0±16.0^{abcde\,\#}$	$114.0±11.6^{de\,\#}$	$114.6±10.2^{de\,\#}$	$111.4±11.1^{de\,\#}$	$105.7±11.4^{\#}$	$105.9±10.7^{\#}$	28.9 (<.001)
Female	$110.0±8.8^{abcde}$	$105.7±7.6^{bde}$	$99.6±9.0^{de}$	$103±11.7^{de}$	95.8±9.4	95.7±10.9	44.7 (<.001)
t(p)	-6.34 (<.001)	-6.98 (<.001)	-12.80 (<.001)	-5.80 (<.001)	-7.82 (<.001)	-7.81 (<.001)	

Note. ^{a}>15-30; ^{b}>30-45; ^{c}>45-60; ^{d}>60-75; ^{e}>75-90; #>female.

Table 2. Player load per minute (PLmin, in $AU \cdot min^{-1}$) in each of the periods in the female and male soccer teams

Gender	0-15	15-30	30-45	45-60	60-75	75-90	F(p)
Male	$12.0±1.9^{abcde\,\#}$	$11.0±1.6^{de\,\#}$	$10.9±1.4^{de\,\#}$	$10.9±1.5^{de\,\#}$	$10.0±1.4^{\#}$	$10.0±1.4^{\#}$	43.6 (<.001)
Female	$10.9±1.4^{abcde}$	$10.3±1.3^{bcde}$	$9.5±1.3^{de}$	$9.8±1.3^{de}$	9.0±1.3	9.0±1.3	34.5 (<.001)
t(p)	-5.75 (<.001)	-4.24 (<.001)	-8.83 (<.001)	-6.53 (<.001)	-5.86 (<.001)	-5.92 (<.001)	

Note. ^{a}>15-30; ^{b}>30-45; ^{c}>45-60; ^{d}>60-75; ^{e}>75-90; #>Female.

Table 3. Indicator of mechanical efficiency (PLm, in AU·m⁻¹) in each of the periods in the female and male soccer teams

Gender	0-15	15-30	30-45	45-60	60-75	75-90	F(p)
Male	.099±.01[bde]	.097±.01[e]	.095±.01	.098±.01[de]	.094±.01	.094±.01	9.2 (<.001)
Female	.099±.01[bde]	.097±.01	.096±.01	.097±.01	.095±.01	.094±.01	4.9 (<.001)
t(p)	-.03 (.974)	.61 (.542)	.18 (.857)	-.88 (.381)	.005 (.996)	.12 (.902)	

Note. [b]>30-45; [c]>45-60; [d]>60-75; [e]>75-90.

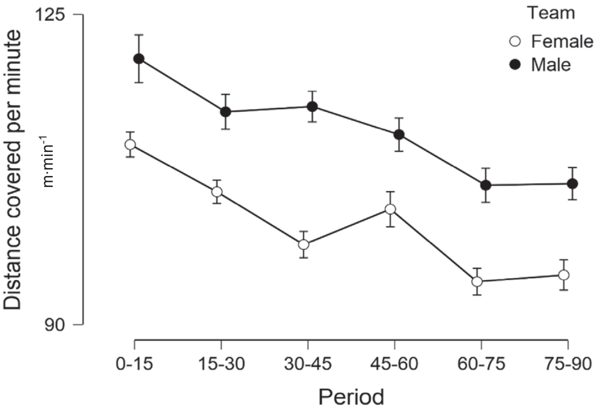


Figure 1. Distance covered per minute (m·min⁻¹) in each of the periods studied in the female and male teams.

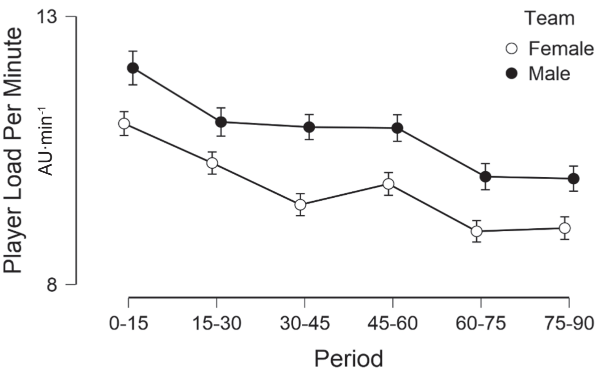


Figure 2. Player Load per minute (AU·min⁻¹) in each of the periods in the female and male soccer teams.

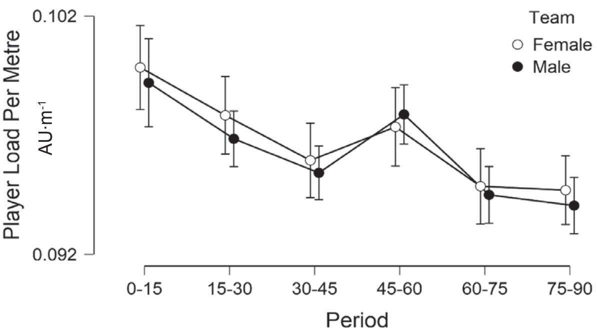


Figure 3. Player Load per metre (AU·m⁻¹) in each of the periods in the female and male soccer teams.

the 45-60 period the PLm was higher than in the 60-75 period (ES: 0.47). Finally, in no period have significant differences been found between genders.

Discussion and conclusions

The study's main aim was to compare the external load and mechanical efficiency between male and female soccer players by analyzing their evolution during the match across 15-minute intervals. The main findings of the study refer to the fact that differences were observed in the DCmin and PLmin, concerning minutes, when both variables were analyzed independently, finding significantly higher values in male soccer. Nevertheless, there were no differences in the mechanical efficiency (PLm) between genders. In addition, a decrease in the three measures was observed, moderate for DCmin and PLmin and low for PLm, as the match progressed. Finally, as the match progressed, more differences in mechanical efficiency (PLm) were found between the male and female teams The similar patterns of decline in both genders in all variables suggest that match time impairment similarly affects both genders as the match progresses and that PLm may be a sensitive indicator of fatigue in both female and male players.

The results obtained in this study in terms of gender differences are in concordance with the literature (Bradley, Dellal, Mohr, Castellano, & Wilkie, 2014; Cardoso de Araújo, Baumgart, Jansen, Freiwald, & Hoppe, 2020; Cardoso de Araújo & Mießen, 2017). The higher values in the physical demands of male than female soccer players are in part due to the physiological-anthropometric characteristics and style of play being different between the genders (Slimani, Baker, Cheour, Taylor, & Bragazzi, 2017). We must be careful when making comparisons that, on many occasions, could generate negative points of view on female soccer with respect to male soccer (Pedersen, Aksdal, & Stalsberg, 2019).

Previous studies have found decreases in the total distance covered and distances covered at high speed in the last minutes of each half of the match (Weston, Drust, & Gregson, 2011). However, recent studies seem to attribute this decrease in activity more to the actual effective playing time than to fatigue that could exist at the end of the match (Carling & Dupont, 2011; Linke, Lames, Link, & Weber, 2018; Morgulev & Galily, 2019; Siegle & Lames, 2012). Even considering only the effective playing time, the distance covered in the second half was greater regardless of the location, the result, and the level of the teams (Rey, et al., 2024). In contrast, Rabbani, Ermidis, Clemente, and Twist, (2024) attribute the decrease in activity to intermittent running capacity. That is, there are no clear conclusions about the reasons for the decrease, as there may be contextual variables that put noise (Castellano, Blanco-Villaseñor, & Álvarez, 2011).

Regarding PLmin, the results of a lower PLmin obtained in the study as the match progressed are in line with previous studies conducted with Australian professional footballers (Rowell, et al., 2018) and with the results obtained in a study carried out in English professional soccer (Barrett, et al., 2016). This can be explained by a lower value of accelerations/decelerations in the course of match-play, understanding that the greater the neuromuscular fatigue, the less speed changes are generated by players (Akenhead, Hayes, Thompson, & French, 2013).

Contrary to the results found in our study, Barrett and colleagues (2016) found an increase in PLm in the last periods of the match. In the current study, we found apparently an increase in mechanical efficiency indicator as the game progressed (e.g., values of PLm decreased progressively trough the 15-min periods). Previous studies have hypothesized that these changes in the mechanical efficiency index (PLm) could reflect a reduction in the length of the step, which would cause an increase in the frequency of steps, and usually a simultaneous reduction in speed (Barrett, et al., 2016; Cormack, Mooney, Morgan, & McGuigan, 2013). Nevertheless, to assess adequately the existence of fatigue (e.g., better mechanical efficiency supposes less fatigue), we should consider the patterns of DCmin and PLmin. PLm is just a ratio between PLmin and DCmin and does not provide additional information. Firstly, the increase in the PLm (worse efficiency) could be justified by the increase in the amount of accelerations, decelerations and changes of direction relative to the distance covered (Dalen, Jørgen, Gertjan, Havard, & Ulrik, 2016) and not byfatigue accumulated throughout the match (Bradley & Noakes, 2013; Paul, Bradley, Nassis, & Paul, 2015). Secondly, decreasing of PLm (better efficiency) could be motivated mainly by distance covered with less pacing or less intermittency (fewer accelerations, decelerations, and change of directions activities), while maintaining the same distance covered by minute.

On the other hand, previous studies have also shown changes in movement patterns and strength in the lower limbs that may be fatigue-induced and related to an increased risk of injury (Lovell, Midgley, Barrett, Carter, & Small, 2013). Acute load in a training session or match and fatigue are closely related and have a positive relationship with the risk of injury (Drew & Finch, 2016; Rogalski, Dawson, Heasman, & Gabbett, 2013). In addition, a higher incidence of injuries was found in the last period of each part of the game (30-45 and 75-90) (Ekstrand, Hägglund, & Waldén, 2011; McCall, et al., 2014). This is of great relevance at the level of optimal performance (Gabbett, 2016), both at the individual and collective level, since being with a minimum number of injuries favours the team's success (Hägglund, et al., 2013). However, there are many variables that can affect behaviour of players in different periods of time (psychological, tactical, match results, weather...) so more studies are needed to determine the influence of fatigue on the change of movement strategy.

One of the study's main limitations is not having another way of calculating fatigue to validate whether the mechanical efficiency that PLm seems to provide is theoretically sensitive to this fatigue. In addition, the study has yet to analyze the three acceleration planes separately, including the differences that could exist between them and their relationship with the movement pattern. On the other hand, the results of the female team can hardly be compared with other studies since there are almost no studies carried out with this gender, highlighting the need for future studies in this population. Finally, the statistical results of the different 15-minute periods should be analyzed with caution, as the changes may be related to fatigue generated in the match or to the physical capacity of the players.

As for the practical applications of the study, the ease of quantifying loads using the method of positioning system devices (GPS) with integrated accelerometers is highlighted. Through this quantification of external loads, we can detect at which moment of the training session or game fatigue appears in each player; that is, we can look at which moment the mechanical efficiency decreases. It would be interesting to see if, with training, we can maintain the PLm values for longer, increasing performance and decreasing the risk of injury. In this way, a more specific readjustment of each player could be carried out based on objective data of external load by positioning on the field.

The study concludes that in all the periods studied, DCmin and PLmin for male soccer players were higher than for female players, but the PLm pattern did not differ between genders. On the other hand, there was a decrease in PLmin and DCmin in the last periods of the match as well as a decrease in the mechanical efficiency indicator (PLm), deducing that a certain degree of fatigue produces the decoupling observed between the variables PLmin and DCmin. As a practical application, monitoring the evolution of fatigue during a match can help verify if an appropriate training process minimizes efficiency deterioration. This information can then be used to implement intervention strategies aimed at enhancing performance or planning recovery.

References

Akenhead, R., Hayes, P.R., Thompson, K.G., & French, D. (2013). Diminutions of acceleration and deceleration output during professional football match play. *Journal of Science and Medicine in Sport*, *16*(6), 556-561. https://doi.org/10.1016/j.jsams.2012.12.005

Akubat, I., Barrett, S., & Abt, G. (2014). Integrating the internal and external training loads in soccer. *International Journal of Sports Physiology and Performance*, *9*(3), 457-462. https://doi.org/10.1123/IJSPP.2012-0347

Akubat, I., Patel, E., Barrett, S., & Abt, G. (2012). Methods of monitoring the training and match load and their relationship to changes in fitness in professional youth soccer players. *Journal of Sports Sciences*, *30*(14), 1473-1480. https://doi.org/10.1080/02640414.2012.712711

Barnes, C., Archer, D.T., Hogg, B., Bush, M., & Bradley, P.S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine*, *35*(13), 1095-1100. https://doi.org/10.1055/s-0034-1375695

Barrett, S., Midgley, A., & Lovell, R. (2014). PlayerLoad™: Reliability, convergent validity, and influence of unit position during treadmill running. *International Journal of Sports Physiology and Performance*, *9*(6), 945-952. https://doi.org/10.1123/ijspp.2013-0418

Barrett, S., Midgley, A., Reeves, M., Joel, T., Franklin, E., Heyworth, R., …, & Lovell, R. (2016). The within-match patterns of locomotor efficiency during professional soccer match play: Implications for injury risk? *Journal of Science and Medicine in Sport*, *19*(10), 810-815. https://doi.org/10.1016/j.jsams.2015.12.514

Batterham, A.M., & Hopkins, W.G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance*, *1*(1), 50-57. https://doi.org/10.1123/ijspp.1.1.50

Boyd, L.J., Ball, K., & Aughey, R.J. (2011). The reliability of minimaxX accelerometers for measuring physical activity in Australian football. *International Journal of Sports Physiology and Performance*, *6*(3), 311-321. https://doi.org/10.1123/ijspp.6.3.311

Bradley, P.S., Dellal, A., Mohr, M., Castellano, J., & Wilkie, A. (2014). Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. *Human Movement Science*, *33*(1), 159-171. https://doi.org/10.1016/j.humov.2013.07.024

Bradley, P.S., & Noakes, T.D. (2013). Match running performance fluctuations in elite soccer: Indicative of fatigue, pacing or situational influences? *Journal of Sports Sciences*, *31*(15), 1627-1638. https://doi.org/10.1080/02640414.2013.796062

Bredt, S. da G.T., Chagas, M.H., Peixoto, G.H., Menzel, H.J., & Andrade, A.G.P. de (2020). Understanding player load: Meanings and limitations. *Journal of Human Kinetics*, *71*(1), 5-9. https://doi.org/10.2478/hukin-2019-0072

Buchheit, M., Gray, A., & Morin, J.B. (2015). Assessing stride variables and vertical stiffness with GPS-embedded accelerometers : Preliminary insights for the monitoring of neuromuscular fatifue on the field. *Journal of Sports Science and Medicine*, *14*(4), 698-701.

Cardoso de Araújo, M., Baumgart, C., Jansen, C.T., Freiwald, J., & Hoppe, M.W. (2020). Sex differences in physical capacities of German Bundesliga soccer players. *Journal of Strength and Conditioning Research*, *34*(8), 2329-2337. doi: 10.1519/JSC.0000000000002662

Cardoso de Araújo, M., & Mießen, K.A.M. (2017). Twenty years of the FIFA Women's World Cup: An outstanding evolution of competitiveness. *Women in Sport and Physical Activity Journal*, *25*(1), 60-64. https://doi.org/10.1123/wspaj.2015-0047

Carling, C. (2013). Interpreting physical performance in professional soccer match-play: Should we be more pragmatic in our approach?. *Sports Medicine*, *43*, 655-663. https://doi.org/10.1007/s40279-013-0055-8

Carling, C., & Dupont, G. (2011). Are declines in physical performance associated with a reduction in skill-related performance during professional soccer match-play? *Journal of Sports Sciences*, *29*(1), 63-71. https://doi.org/10.1080/02640414.2010.521945

Casamichana, D., Castellano, J., Calleja-Gonzalez, J., Roman, J.S., & Castagna, C. (2013). Relationship between indicators of training load in soccer players. *Journal of Strength and Conditioning Research*, *27*(2), 369-374. https://doi.org/10.1519/JSC.0b013e3182548af1

Castellano, J., Blanco-Villaseñor, A., & Álvarez, D. (2011). Contextual variables and time-motion analysis in soccer. *International Journal of Sports Medicine*, *32*(6), 415-421. https://doi.org/10.1055/s-0031-1271771

Cormack, S.J., Mooney, M.G., Morgan, W., & McGuigan, M.R. (2013). Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. *International Journal of Sports Physiology and Performance*, *8*(4), 373-378. https://doi.org/10.1123/ijspp.8.4.373

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. *Sports Medicine*, *43*(10), 1025-1042. https://doi.org/10.1007/s40279-013-0069-2

Dalen, T., Jørgen, I., Gertjan, E., Havard, H.G., & Ulrik, W. (2016). Player load, acceleration, and deceleration during forty-five competitive matches of elite soccer. *Journal of Strength and Conditioning Research*, *30*(2), 351-359. https://doi.org/10.1519/JSC.0000000000001063

Dobson, B.P., & Keogh, J.W.L. (2007). Methodological issues for the application of time-motion analysis research. *Strength and Conditioning Journal*, *29*(2), 48-55. https://doi.org/10.1519/1533-4295(2007)29[48:miftao]2.0.co;2

Drew, M.K., & Finch, C.F. (2016). The relationship between training load and injury, illness and soreness: A systematic and literature review. *Sports Medicine*, *46*(6), 861-883. https://doi.org/10.1007/s40279-015-0459-8

Ekstrand, J., Hägglund, M., & Waldén, M. (2011). Epidemiology of muscle injuries in professional football (soccer). *American Journal of Sports Medicine*, *39*(6), 1226-1232. https://doi.org/10.1177/0363546510395879

Gabbett, T.J. (2016). The training-injury prevention paradox: Should athletes be training smarter and harder? *British Journal of Sports Medicine*, *50*(5), 273-280. https://doi.org/10.1136/bjsports-2015-095788

Gabbett, T.J., Nassis, G.P., Oetter, E., Pretorius, J., Johnston, N., Medina, D., …, & Ryan, A. (2017). The athlete monitoring cycle: A practical guide to interpreting and applying training monitoring data. *British Journal of Sports Medicine*, *51*(20), 1451-1452. https://doi.org/10.1136/bjsports-2016-097298

Gómez-Carmona, C.D., Bastida-Castillo, A., Ibáñez, S.J., & Pino-Ortega, J. (2020). Accelerometry as a method for external workload monitoring in invasion team sports. A systematic review. *PLoS ONE*, *15*(8), e0236643. https://doi.org/10.1371/journal.pone.0236643

Hägglund, M., Waldén, M., Magnusson, H., Kristenson, K., Bengtsson, H., & Ekstrand, J. (2013). Injuries affect team performance negatively in professional football: An 11-year follow-up of the UEFA Champions League injury study. *British Journal of Sports Medicine*, *47*(12), 738-742. https://doi.org/10.1136/bjsports-2013-092215

Lacome, M., Simpson, B.M., & Buchheit, M. (2018). Monitoring training player-tracking technology: Still on the road to Rome. *Aspetar Sports Medicine Journal*, *7*, 54-66.

Linke, D., Lames, M., Link, D., & Weber, H. (2018). Decline in match running performance in football is affected by an increase in game interruptions. *Journal of Sports Science and Medicine*, *17*(4), 662-667. Retrieved from https://pmc.ncbi.nlm.nih.gov/articles/PMC6243615/

Lovell, R., Midgley, A., Barrett, S., Carter, D., & Small, K. (2013). Effects of different half-time strategies on second half soccer-specific speed, power and dynamic strength. *Scandinavian Journal of Medicine and Science in Sports*, *23*(1), 105-113. https://doi.org/10.1111/j.1600-0838.2011.01353.x

Martínez-Lagunas, V., Niessen, M., & Hartmann, U. (2014). Women's football: Player characteristics and demands of the game. *Journal of Sport and Health Science*, *3*(4), 258-272. https://doi.org/10.1016/j.jshs.2014.10.001

McCall, A., Carling, C., Nedelec, M., Davison, M., Le Gall, F., Berthoin, S., & Dupont, G. (2014). Risk factors, testing and preventative strategies for non-contact injuries in professional football: Current perceptions and practices of 44 teams from various premier leagues. *British Journal of Sports Medicine*, *48*(18), 1352-1357. https://doi.org/10.1136/bjsports-2014-093439

McLaren, S.J., Macpherson, T.W., Coutts, A.J., Hurst, C., Spears, I.R., & Weston, M. (2018). The relationships between internal and external measures of training load and intensity in team sports: A meta-analysis. *Sports Medicine*, *48*(3), 641-658. https://doi.org/10.1007/s40279-017-0830-z

Morgulev, E., & Galily, Y. (2019). Analysis of time-wasting in English Premier League football matches: Evidence for unethical behavior in final minutes of close contests. *Journal of Behavioral and Experimental Economics*, *81*, 1–8. https://doi.org/10.1016/j.socec.2019.05.003

Paul, D.J., Bradley, P.S., Nassis, G.P., & Paul, D.J. (2015). Factors impacting match running performances of elite soccer players: Shedding some light on the complexity. *International Journal of Sports Physiology and Performance*, *10*(4), 516-519. doi: 10.1123/IJSPP.2015-0029

Pedersen, A.V., Aksdal, I.M., & Stalsberg, R. (2019). Scaling demands of soccer according to anthropometric and physiological sex differences: A fairer comparison of men's and women's soccer. *Frontiers in Psychology*, *10*, 762. https://doi.org/10.3389/fpsyg.2019.00762

Polglaze, T., Dawson, B., Hiscock, D.J., & Peeling, P. (2015). A comparative analysis of accelerometer and time-motion data in elite men's hockey training and competition. *International Journal of Sports Physiology and Performance*, *10*(4), 446-451. https://doi.org/10.1123/ijspp.2014-0233

Rabbani, A., Ermidis, G., Clemente, F.M., & Twist, C. (2024). Variability of external load measures during soccer match play: Influence of player fitness or pacing? *International Journal of Sports Physiology and Performance*, *19*(4), 340-346. https://doi.org/10.1123/ijspp.2023-0243

Rago, V., Brito, J., Figueiredo, P., Costa, J., Barreira, D., Krustrup, P., & Rebelo, A. (2020). Methods to collect and interpret external training load using microtechnology incorporating GPS in professional football: A systematic review. *Research in Sports Medicine*, *28*(3), 437-458. https://doi.org/10.1080/15438627.2019.1686703

Ramos, G.P., Nakamura, F.Y., Penna, E.M., Wilke, C.F., Pereira, L.A., Loturco, I., …, & Coimbra, C.C. (2019). Activity profiles in U17, U20, and senior women's Brazilian national soccer teams during international competitions: Are there meaningful differences? *Journal of Strength and Conditioning Research*, *33*(12), 3414-3422. https://doi.org/10.1519/JSC.0000000000002170

Reche-Soto, P., Cardona-Nieto, D., Diaz-Suarez, A., Bastida-Castillo, A., Gomez-Carmona, C., Garcia-Rubio, J., & Pino-Ortega, J. (2019). Player load and metabolic power dynamics as load quantifiers in soccer. *Journal of Human Kinetics*, *69*(1), 259-269. https://doi.org/10.2478/hukin-2018-0072

Rey, E., Kalén, A., Lorenzo-Martínez, M., López-Del Campo, R., Nevado-Garrosa, F., & Lago-Peñas, C. (2024). Elite soccer players do not cover less distance in the second half of the matches when game interruptions are considered. *Journal of Strength and Conditioning Research*, *38*(4), 709-713. https://doi.org/10.1519/JSC.0000000000003935

Rogalski, B., Dawson, B., Heasman, J., & Gabbett, T.J. (2013). Training and game loads and injury risk in elite Australian footballers. *Journal of Science and Medicine in Sport*, *16*(6), 499-503. https://doi.org/10.1016/j.jsams.2012.12.004

Rowell, A.E., Aughey, R.J., Clubb, J., & Cormack, S.J. (2018). A standardized small sided game can be used to monitor neuromuscular fatigue in professional A-league football players. *Frontiers in Physiology*, *9*, 1011. https://doi.org/10.3389/fphys.2018.01011

Siegle, M., & Lames, M. (2012). Game interruptions in elite soccer. *Journal of Sports Sciences*, *30*(7), 619-624. https://doi.org/10.1080/02640414.2012.667877

Slimani, M., Baker, J.S., Cheour, F., Taylor, L., & Bragazzi, N.L. (2017). Steroid hormones and psychological responses to soccer matches: Insights from a systematic review and meta-analysis. *PLoS ONE*, *12*(10), e0186100. https://doi.org/10.1371/journal.pone.0186100

Strauss, A., Sparks, M., & Pienaar, C. (2019). The use of GPS analysis to quantify the internal and external match demands of semi-elite level female soccer players during a tournament. *Journal of Sports Science and Medicine*, *18*(1), 73-81.

Theodoropoulos, J.S., Bettle, J., & Kosy, J.D. (2020). The use of GPS and inertial devices for player monitoring in team sports: A review of current and future applications. *Orthopedic Reviews*, *12*(1), 7863. https://doi.org/10.4081/or.2020.7863

Weston, M., Drust, B., & Gregson, W. (2011). Intensities of exercise during match-play in FA Premier League referees and players. *Journal of Sports Sciences*, *29*(5), 527-532. https://doi.org/10.1080/02640414.2010.543914

Winter, E. M., & Maughan, R. J. (2009). Requirements for ethics approvals. *Journal of sports sciences, 27*(10), 985. https://doi.org/10.1080/02640410903178344

Submitted: April 17, 2024
Accepted: August 18, 2024
Published Online First: December 16, 2024

Correspondence to:
Eider Barba
University of the Basque Country
Physical Education and Sport Department
C/ Portal de Lasarte 71, CP: 01007, Vitoria-Gasteiz, Spain
Phone: +34 00 688660268
Email: eider.barba@ehu.eus

Acknowledgements

The authors gratefully acknowledge the support of a Spanish government Project entitled Optimisation of the preparation process and competitive performance in Team Sports based on multi-modal and multi-level data integration by intelligent models [PID2023-147577NB-I00] for the four years 2024-2027, in the 2023 call for grants for “KNOWLEDGE GENERATION PROJECTS”, in the framework of the State Program to Promote Scientific-Technical Research and its Transfer, of the State Plan for Scientific, Technical and Innovation Research of the Ministry of Science, Innovation and Universities (MCIU).

EFFECTS OF A WEB-BASED NEED-SUPPORTIVE INTERVENTION PROGRAMME ON PHYSICAL EDUCATION TEACHER OUTCOMES

Henri Tilga, Linda Marii Aljasmäe, Hasso Paap, Pille-Riin Meerits, and Andre Koka

Institute of Sports Sciences and Physiotherapy, Faculty of Medicine, University of Tartu, Tartu, Estonia

Original scientific paper
DOI 10.26582/k.56.2.12

Abstract:

Interventions aimed at enhancing need-supportive behaviours have predominantly focused on assessing their effects on student outcomes, thereby placing comparatively less emphasis on gains experienced by teachers. This study investigated whether a web-based need-supportive intervention programme for physical education (PE) teachers would also provide significant gains in enhancing PE teachers need-supportive behaviours, psychological need satisfaction, intrinsic motivation to teach, teaching efficacy and reducing their controlling behaviours. Participants were 74 PE teachers (54 women). Their average age was 46.04 years (SD = 12.64), and they had an average teaching experience of 17.33 years (SD = 13.83). Participants were allocated into experimental and control conditions. PE teachers in the experimental group completed a four-week web-based need-supportive intervention programme. Results demonstrated that the experimental group PE teachers demonstrated significant gains in their autonomy support, competence support and teaching efficacy compared to the control group PE teachers within a one-month follow-up. These results suggest that our web-based need-supportive intervention programme for PE teachers was partially effective to produce gains for PE teachers themselves.

Key words: *autonomy support, competence support, relatedness support, controlling behaviour, motivation, teaching efficacy*

Introduction

Enhancing autonomy supportive behaviours among physical education (PE) teachers plays a crucial role in shaping experiences of intrinsic motivation among their students (Raabe, Schmidt, Carl, & Höner, 2019; Vasconcellos, et al., 2020; White, et al., 2021). The possible mechanism behind this process is most likely that autonomy supportive behaviours enhance students' experiences of basic psychological need satisfaction, and, in turn, students experience higher levels of intrinsic motivation (Kalajas-Tilga, Koka, Hein, Tilga, & Raudsepp, 2020). Moreover, recent research has demonstrated that not only students, but also teachers themselves gain various benefits when they become more autonomy supportive towards their students (Cheon, Reeve, Yu, & Jang, 2014; Tilga, Kalajas-Tilga, Hein, Raudsepp, & Koka, 2021a). However, based on the self-determination theory (SDT; Ryan & Deci, 2020), one should aim to fulfil all three basic psychological needs for autonomy, competence, and relatedness. Based on recent classification system of need supportive behaviours (Teixeira, et al., 2020), a need supportive intervention programme for PE teachers was developed, indicating several important gains in students' experiences after their teachers participated in this need supportive intervention programme. One might argue that teachers also gain even greater benefits when they learn how to become more need supportive. However, there is no research so far testing the effectiveness of not only autonomy-supportive training, but also competence supportive and relatedness supportive training on teacher's outcomes. Thus, the current study was designed to test the efficacy of a need supportive intervention programme on PE teachers' outcomes.

Self-determination theory (Ryan & Deci, 2020) posits three primary psychological needs—autonomy, competence, and relatedness—that are essential for fostering intrinsic motivation and well-being. Autonomy refers to the need to feel a sense of volition and choice in one's actions; competence involves the need to feel effective and capable within one's environment; and relatedness is the need to feel connected and supported by others (Ryan & Deci, 2020). In educational contexts, interventions that aim to enhance need-supportive behaviours, such as autonomy support, typically focus on helping teachers provide students with choice, encourage self-initiation, and respect students' perspectives (Vasconcellos, et al., 2020). When these pre-intervention (antecedent) variables, such as autonomy support, are strengthened, they positively impact post-intervention (consequence) variables, like students' need satisfaction and motivation. Research has demonstrated that fulfilling these psychological needs leads to increased intrinsic motivation, improved well-being, and higher engagement in students (Kalajas-Tilga, et al., 2020; Cheon, et al., 2014) and can concurrently enhance teachers' own teaching efficacy and reduce controlling behaviours (Tilga, et al., 2021a).

In this research, SDT (Ryan & Deci, 2020) was used as a theoretical background for explaining how autonomy supportive, competence supportive and relatedness supportive behaviours exhibited by PE teachers is beneficial to teachers themselves. Based on the SDT, individuals strive to satisfy their basic psychological needs for autonomy, competence, and relatedness. Fulfilment of these needs is related to intrinsic motivation and, in turn, to various adaptive outcomes. A great number of studies have shown that students benefit from receiving autonomy-supportive teaching (e.g., Raabe, et al., 2019). However, only a few of recent studies have demonstrated that teachers also experience several adaptive outcomes when they provide need support (Cheon, et al., 2014; Tilga, et al., 2021a). For example, Cheon and colleagues (2014) found that teachers who participated in an autonomy-supportive face-to-face intervention demonstrated after the intervention greater teaching motivation. Moreover, teachers also reported higher psychological need satisfaction, autonomous motivation and intrinsic goals (Cheon, et al., 2014). Furthermore, teachers perceived greater level of overall well-being, including increased vitality and job satisfaction, but lower emotional and physical exhaustion. Additionally, their teaching skills, as reflected in teaching efficacy, demonstrated increase. In another study by Tilga and colleagues (2021a), it was found that after participating in a web-based multidimensional autonomy-supportive intervention programme teachers reported significant gains in their multidimensional autonomy-supportive behaviours and in teaching efficacy for students' engagement. Similarly to a study by Tilga and colleagues (2021a), we also adopt a web-based approach in this study for the following reasons: (1) web-based interventions are cost-effective; (2) web-based interventions are convenient and easily accessible; (3) web-based interventions can afford attendees' anonymity (Murray, 2012). The use of web-based interventions has become increasingly prevalent in the field of PE and beyond, providing a flexible and accessible platform for training. This study adopts a web-based approach for several practical and empirical reasons. First, web-based interventions are often more cost-effective than in-person programmes, as they reduce the need for physical materials, venues, and travel expenses (Murray, 2012). This cost-efficiency makes it possible to reach a wider audience, particularly in cases where resources may be limited. Second, web-based interventions offer convenience and accessibility, allowing participants to engage with the content at times and locations that suit them, which is particularly valuable for busy professionals like PE teachers (Tilga, Kalajas-Tilga, H., Hein, V., & Koka, 2021c). Additionally, online platforms enable a degree of anonymity that can encourage more open participation, as teachers may feel more comfortable engaging with the content privately (Murray, 2012). Empirical evidence also supports the effectiveness of web-based training in promoting autonomy-supportive behaviours among PE teachers (Tilga, et al., 2021a), suggesting that these digital interventions can successfully enhance the quality of teaching and, consequently, students' outcomes in PE. This combination of accessibility, cost-effectiveness, and supportive evidence underlines the decision to implement a web-based intervention in the present study.

Most of the SDT-driven intervention programmes conducted in the context of PE have focused on enhancing PE teachers' autonomy-supportive behaviours (e.g., Raabe, et al., 2019; Su & Reeve, 2011). Only few studies have aimed to educate PE teachers how to provide autonomy, competence, and relatedness support to their students (Paap, Koka, Meerits, & Tilga, 2024). To our best knowledge, there is also one effective need-supportive intervention programme for parents to increase their need-supportive behaviour towards their children (Meerits, Tilga, & Koka, 2022, 2023). Adopting need-supportive techniques from a classification system provided by Teixeira and colleagues (2020) was aimed in this study to enhance PE teachers' autonomy, competence and relatedness support towards their students. In total, there are 21 motivational and behavioural change techniques (MBCT) proposed by Teixeira and colleagues (2020): there are seven autonomy support techniques, seven competence support techniques and seven relatedness support techniques. There are several reasons why we expect that it is beneficial to PE teachers to adopt these need-supportive techniques. Firstly, PE teachers who have successfully passed this need-supportive intervention programme most likely exhibit higher teaching efficiency. The reason for this is that this need-supportive intervention most likely provides teachers with acknowledged teaching strategies that help to deliver classroom instructions more efficiently. Secondly, there might be reciprocal associations between students' and teachers' outcomes (e.g., Jang, Kim, & Reeve, 2012; Pelletier, Séguin-Lévesque, & Legault, 2002; Reeve, 2013). Specifically, it is likely that when students experience gains in their motivational outcomes, then their teachers also might exhibit higher experiences in their motivational outcomes. Thirdly, previous studies have shown that teachers with higher scores of need-supportive behaviours are more likely to report greater motivational outcomes (Roth, Assor, Kanat-Maymon, & Kaplan, 2007; Stebbings, Taylor, Spray, & Ntoumanis, 2012; Taylor, Ntoumanis, & Standage, 2008). Based on this, one might argue that giving need support to other would enhance the giver's own motivational experiences.

The present study

The present study seeks to address a significant gap in the literature on need-supportive interventions for physical education (PE) teachers by focusing on a web-based approach. While traditional, face-to-face interventions have shown efficacy in promoting autonomy-supportive behaviours among teachers (Cheon, et al., 2014), there is a relative scarcity of research examining the impact of web-based interventions in this context. Given that web-based approaches offer advantages such as cost-effectiveness, accessibility, and convenience (Murray, 2012), they hold promise for broader application in teacher training programmes. Despite the potential benefits, few studies have rigorously tested the effects of web-based need-supportive interventions on PE teachers' own psychological experiences, such as autonomy support, competence support, and relatedness support, as well as on critical outcomes like teaching efficacy, motivation, and behaviour management skills (Tilga, et al., 2021a).

Therefore, this study aims to test the efficacy of a web-based intervention programme specifically designed to enhance PE teachers' need-supportive behaviours. Based on SDT (Ryan & Deci, 2020) and previous research in autonomy-supportive interventions (Cheon, et al., 2014; Tilga, et al., 2021c), we hypothesize that, PE teachers in the experimental group, compared to PE teachers in the control group, would perceive:

H_1: higher provision of autonomy, competence, and relatedness support at follow-up.
H_2: lower controlling behaviours at follow-up.
H_3: higher psychological need satisfaction at follow-up.
H_4: higher intrinsic motivation to teach at follow-up.
H_5: higher teaching efficacy at follow-up.

By addressing these hypotheses, this study contributes to the growing field of digital interventions in education, providing insights into how web-based platforms can enhance teacher behaviour and potentially improve students' outcomes in physical education settings.

Methods

Participants

Participants were 74 PE teachers (20 men and 54 female) from 90 schools throughout Estonia who voluntarily agreed to participate in the study. Teachers were on average 46.04 years old (SD = 12.64, range 22-68), and had an average of 17.33 years of teaching experience (SD = 13.83, range = 1-45). These 74 PE teachers expressed an interest in the study via survey they received that provided them detailed information about the survey, followed by agreement to participate in this survey. There was approval from the local ethical committee obtained to conduct the survey (approval number: 327/T- 4).

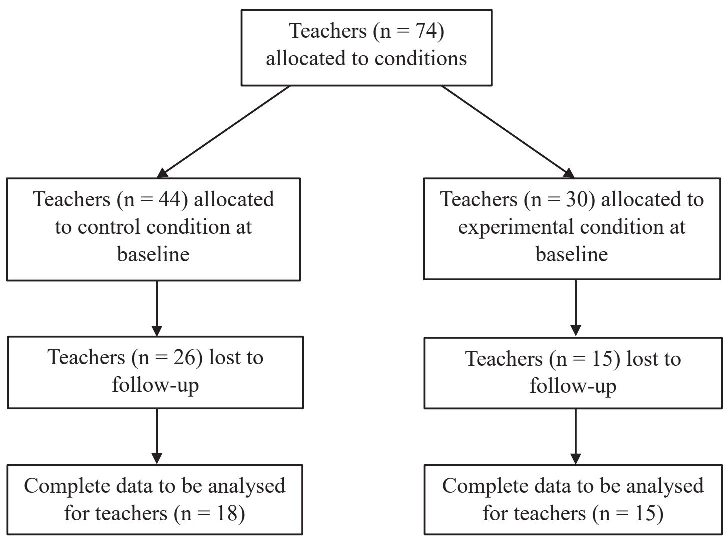


Figure 1. Participant flow diagram.

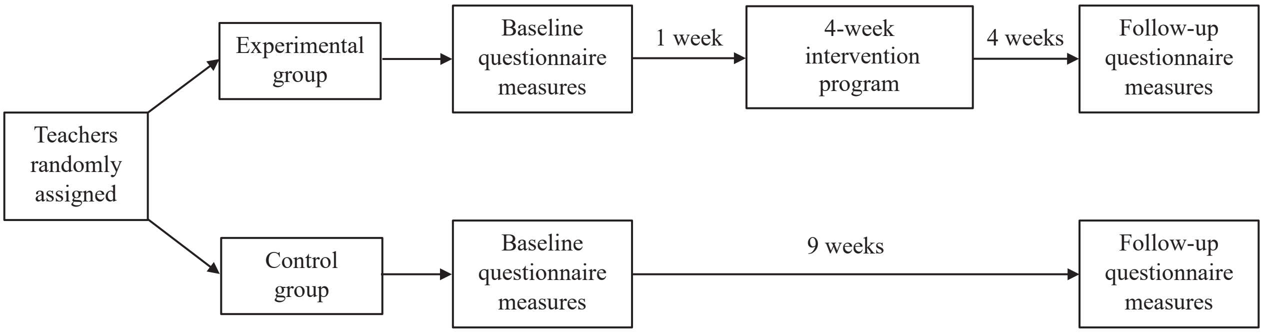


Figure 2. Overall study design.

Procedure

A randomized controlled research design was adopted in which teachers were randomly assigned to either the experimental or control group. More detailed participant selection flow chart appears in Figure 1. At baseline, 74 PE teachers completed a questionnaire about their perceptions of self-reported autonomy, competence, and relatedness need-supportive behaviours, self-reported controlling behaviours, self-reported perceptions of their own basic psychological need satisfaction, self-reported intrinsic motivation to teach and self-reported teaching efficacy. One week later, the web-based need-supportive four-week intervention programme for the PE teachers was initiated in the experimental group. PE teachers completed the follow-up questionnaire four weeks after the intervention ended (see Figure 2 for the overall study design).

Measures

Self-reported need support by PE teachers. PE teachers reported providing of autonomy support to their students by filling in the modified version of *Perceived Autonomy Support Scale for Exercise Setting* (PASSES; Hagger, et al., 2007), shortened and modified by Kalajas-Tilga and colleagues (2022a). PE teachers reported provision of competence and relatedness support to their students by filling in the *Perceived Psychological Needs Support from the Teacher in PE* (PPNST-PE; Standage, Duda, & Ntoumanis, 2005), adapted to Estonian context by Viira and Koka (2012). Example items are following: “I offer students choices and how to be physically active” (autonomy support), “I help students feel that they are competent at physical education” (competence support), and “I make my students feel that I respect them” (relatedness support). In this study, 7-point Likert scale was used ranging from “1 – completely disagree with the statement” to “7 – completely agree with the statement”. Previous studies have shown that PASSES and PPNST-PE are reliable and valid (e.g., Kalajas-Tilga, et al., 2022a, 2022b).

Self-reported controlling behaviours by PE teachers. PE teachers reported provision of controlling behaviours to their students by filling in the modified version of multidimensional *Controlling Coach Behaviours Scale* (CCBS; Bartholomew, Ntoumanis, & Thøgersen-Ntoumani, 2010), adapted to PE (Hein, Koka, & Hagger, 2015). An example items is following: “I try to control everything the students do”. In this study, 7-point Likert scale was used ranging from “1 – completely disagree with the statement” to “7 – completely agree with the statement”. Previous studies have shown that CCBS is reliable and valid (e.g., Koka, Tilga, Kalajas-Tilga, Hein, & Raudsepp, 2019; Koka, Tilga, Kalajas-Tilga, Hein, & Raudsepp, 2020; Tilga, Kalajas-Tilga, Hein, Raudsepp, & Koka, 2020a).

Self-reported basic psychological needs satisfaction. PE teachers reported their own basic psychological needs satisfaction by filling in the modified version of the *Basic Psychological Need Satisfaction and Need Frustration Scale* (BPNSNF, Chen, et al., 2015), adapted to PE (Haerens, Aelterman, Vansteenkiste, Soenens, & Van Petegem, 2015). PE teachers were presented with a common stem: “During the teaching …”, followed by the items tapping three subscales: need satisfaction for autonomy (e.g., “ … I felt freedom of choice in my actions”), competence (e.g., “ … I felt I could successfully complete difficult tasks”), and relatedness (e.g., “ … I felt that the students I cared about also cared about me”). In this study, 7-point Likert scale was used ranging from “1 – completely disagree with the statement” to “7 – completely agree with the statement”. Previous research has supported the reliability and factor structure of the BPNSNF (e.g., Tilga, et al., 2020a).

Self-reported intrinsic motivation to teach. PE teachers reported intrinsic reasons to teach by filling in the modified version of the *Perceived Locus of Causality* (PLOC, Goudas, Biddle, & Fox, 1994), adapted by Cheon and colleagues (2014). An example items is following: “I teach because I enjoy it”. In this study, 7-point Likert scale was used ranging from “1 – completely disagree with the statement” to “7 – completely agree with the statement”. Previous research has supported the reliability of the PLOC (e.g., Tilga, Kalajas-Tilga, Hein, Raudsepp, & Koka 2021b).

Self-reported teaching efficacy. PE teachers reported their teaching efficacy by filling in the short form of the *Teachers’ Sense of Efficacy Scale* (TSES, Tschannen-Moran & Hoy, 2001). An example items is following: “I can contribute so that students feel that they can cope with their school work”. In this study, 9-point Likert scale was used ranging from “1 – not at all true” to “9 – very true”. Previous research has supported the reliability of the TSES (e.g., Tilga, et al., 2021a).

Web-based need-supportive intervention programme

The experimental group PE teachers were asked to participate in a web-based need-supportive intervention programme. It was designed as a four-week online training aimed at introducing various need-supportive behaviour techniques for PE teachers with the aim to support students’ intrinsic motivation towards physical activity during PE classes. The online intervention programme consists of 21 short instructional videos (each video averaging four to five minutes in length), in which examples are provided to give PE teachers knowledge about these behaviour techniques and how to support students’ psychological basic needs for autonomy, competence, and relatedness in PE class. The videos are structured as follows: first, an explanation is given about the basic psychological need that the introduced technique supports; second, the content of the behaviour technique is briefly introduced; third, a sample situation of the negative application of the behaviour technique is presented; and fourth, a sample situation of the positive application of the behaviour technique is presented. The instructional videos are compiled based on the results of scientific literature (Teixeira, et al., 2020).

In the first week of the web-based intervention programme, PE teachers were required to review six videos as part of the intervention programme. The focus was on the following motivational techniques: (1) elicit perspectives on condition or behaviour (supporting the need for autonomy), (2) explore life aspirations and values (supporting the need for autonomy), (3) acknowledge and respect perspectives and feelings (supporting the need for relatedness), (4) encourage asking questions (supporting the need for relatedness), (5) clarify expectations (supporting the need for competence), and (5) help develop a clear and concrete plan of action (supporting the need for competence). To ensure whether PE teachers understood the learning materials or not, a test consisting of nine multiple-choice questions had to be taken after watching the videos. At the end of the week, a forum post from PE teachers was required, analysing the application of the learned techniques during the week.

In the second week of the web-based intervention programme, PE teachers needed to familiarize themselves with five videos, and the intervention programme focused on the following techniques: (1) use non-controlling, informational language (supporting the need for autonomy), (2) provide choice (supporting the need for autonomy), (3) acknowledge and respect perspectives and feelings (supporting the need for relatedness), (4) assist in setting optimal challenge (supporting the need for competence), and (5) offer constructive, clear, and relevant feedback (supporting the need for competence). After watching the videos, a test for the second week consisting of five multiple-choice questions had to be completed. At the end of the week, a forum post from PE teachers was required, analysing the application of the learned techniques during the week.

In the third week of the web-based intervention programme, PE teachers had to work through five videos, and the techniques taught in the course were: (1) prompt identification of sources of pressure for behaviour change (supporting the need for autonomy), (2) demonstrate/show interest in the person (supporting the need for relatedness), (3) prompt identification and seek available social support (supporting the need for relatedness), (4) address obstacles for change (supporting the need for competence), and (5) explore ways of dealing with pressure (supporting the need for competence). After watching the videos, a test for the third week consisting of five multiple-choice questions had to be completed. At the end of the week, a forum post from PE teachers was required, analysing the application of the learned techniques during the week.

In the fourth week of the web-based intervention programme, teachers needed to familiarize themselves with five videos, where the techniques taught for the week were: (1) provide a meaningful rationale (supporting the need for autonomy), (2) encourage the person to experiment and self-initiate the behaviour (supporting the need for autonomy), (3) show unconditional regard (supporting the need for relatedness), (4) providing opportunities for ongoing support (supporting the need for relatedness), and (5) promote self-monitoring (supporting the need for competence). After watching the videos, a test for the fourth week consisting of two multiple-choice questions had to be completed. At the end of the week, a forum post from PE teacher was required, analysing the application of the learned techniques during the week.

Data analysis

The SPSS Statistics version 23.0 statistical package was used for statistical analyses. The skewness and kurtosis estimates of each item were estimated, which ranged between –2 to + 2 and were considered acceptable to support normal univariate distribution (Byrne, 2010). A series of separate confirmatory factor analyses (CFAs) were conducted to test the validity of the proposed factor structure of the scales used in this study. The following indices were used: the comparative fit index (CFI), the Bentler–Bonett non-normed fit index (NNFI), and the root mean square error of approximation (RMSEA). An acceptable fit of the data with the hypothesised model was indicated by values ≥ .90 for the CFI and NNFI, and value ≤ .08 for the RMSEA (Hu & Bentler, 1999). The reliability of the scales in this study was assessed using Cronbach's alpha, with values ranging from .70 to .95, indicating acceptable internal consistency (Nunnally, 1978). For preliminary analysis the chi-square tests and independent samples t-tests were performed to examine baseline differences between the study groups (i.e., randomization check) and to examine differences between the group of those who remained in the study and the group of those who were lost to follow-up (i.e., attrition check). For main analysis a series of analyses of covariance (ANCOVAs) were performed to examine the effectiveness of the web-based need-supportive intervention programme on PE teachers' psychological experiences. Specifically, variables of PE teachers' self-reported autonomy support, competence support, relatedness support, controlling behaviours, psychological needs satisfaction, intrinsic motivation to teach, and teaching efficacy were used as dependent variables, whereas study group (i.e., experimental group and control group) was used as the independent variable. The respective baseline variable was included as a covariate in each of the ANCOVA analysis. Partial eta squared was used as a measure of the effect size for ANCOVA.

Results

Preliminary analysis

Reliability and validity of the study instruments. Results of a series of CFAs for each of the study measures indicated acceptable goodness-of-fit statistics: PASSES (CFI = .94; NNFI = .93; RMSEA = .07), PPNST-PE (CFI = .95; NNFI = .94; RMSEA = .07), CCBS (CFI = .94; NNFI = 94; RMSEA = .07), BPNSNF (CFI = .96; NNFI = .94; RMSEA = .06), PLOC (CFI = .91; NNFI = .90; RMSEA = .08), TSES (CFI = .92; NNFI = .92; RMSEA = .08). Cronbach's alpha values of the scales used in the study were as follows: PASSES (α = .74), PPNST-PE (α = .86), CCBS (α = .79), BPNSNF (α = .89), PLOC (α = .71), TSES (α = .73). Please note that all the scales used in this study were used in the context of PE and PE teachers used these scales to provide self-reported experiences. Please see the section Measures for more specific information of which part and how these scales were used in this study.

Randomization check. The characteristics of the participants at baseline are reported in Table 1. Results of the independent samples t-test showed that there were no significant differences in the study variables between the study groups (i.e., experimental and control group) at baseline (*p*s>.06). Also, there were no significant differences in the groups of male and female participants in the experimental and control groups (χ^2 = 0.349, *p*=.61).

Attrition check. The characteristics of the participants who remained in the study and those who were lost to follow-up are reported in Table 2. Results of the independent samples t-test demonstrated that there were no significant differences at baseline between those who remained in the study and those who were lost to follow-up (*p*s>.22). Also, there were no significant sex differences between the participants who remained in the study and those who were lost to follow-up (χ^2 = 0.324, p=.61).

Main analysis

Between-group change comparisons. The results of the ANCOVA are reported in Table 3. Results indicated that PE teachers in the experimental group reported significantly higher provision of autonomy support (p<.002), competence support (p<.009), and higher experiences of teaching efficacy (p<.006) at follow-up compared

Table 1. Comparisons of the baseline variables between the experimental and control group

Variable	Experimental group (n = 30)	Control group (n = 44)	t or χ^2	p
	M (SD)	M (SD)		
Autonomy support	6.11 (0.62)	6.10 (0.54)	t = 0.65	.31
Controlling behaviour	3.79 (1.07)	3.90 (0.90)	t = -0.48	.33
Competence support	6.61 (0.41)	6.40 (0.61)	t = 1.67	.06
Relatedness support	6.51 (0.54)	6.36 (0.62)	t = 1.10	.32
Psychological need satisfaction	5.87 (0.56)	5.65 (0.64)	t = 1.49	.41
Intrinsic motivation to teach	6.23 (0.65)	5.81 (0.87)	t = 1.57	.13
Teaching efficacy	7.55 (0.88)	7.29 (1.03)	t = 1.10	.42
Gender	7/23	13/31	χ^2 = 0.349	.60

Table 2. Comparisons of the variables between those who remained in the study and those who were lost to follow-up

Variable	Remained in the study (n = 33)	Lost in follow-up (n = 41)	t or χ^2	p
	M (SD)	M (SD)		
Autonomy support	6.03 (0.60)	6.17 (0.54)	t = -1.06	.29
Controlling behaviour	3.87 (0.98)	3.85 (0.97)	t = 0.057	.96
Competence support	6.51 (0.55)	6.47 (0.55)	t = 0.35	.72
Relatedness support	6.38 (0.66)	6.45 (0.53)	t = -0.52	.61
Psychological need satisfaction	5.77 (0.71)	5.71 (0.53)	t = 0.40	.69
Intrinsic motivation to teach	6.13 (0.61)	5.90 (0.95)	t = 1.23	.22
Teaching efficacy	7.54 (1.04)	7.28 (0.92)	t = 1.16	.25
Gender	10/23	10/31	χ^2 = 0.324	.61

Table 3. Comparisons of the variables between study groups at follow-up

Variable	Experimental group (n = 15)	Control group (n = 18)	F (1,33)	p
	M (SD)	M (SD)		
Autonomy support	6.65 (0.50)	6.07 (0.47)	11.43	.002
Controlling behaviour	3.15 (1.12)	3.67 (1.14)	1.69	.203
Competence support	6.71 (0.58)	6.13 (0.59)	7.82	.009
Relatedness support	6.50 (0.50)	6.18 (0.12)	3.50	.071
Psychological need satisfaction	5.73 (0.58)	5.50 (0.51)	1.29	.266
Intrinsic motivation to teach	5.89 (0.89)	5.40 (0.89)	2.22	.146
Teaching efficacy	8.23 (1.01)	7.19 (0.98)	8.93	.006

to PE teachers in the control group. No significant study group effects were found on provision of relatedness support, controlling behaviour, experiences of psychological needs satisfaction, and intrinsic motivation to teach.

Discussion and conclusions

This study aimed to investigate whether the web-based need-supportive intervention programme for PE teachers led to changes in PE teachers' provision of autonomy support, competence support, relatedness support, controlling behaviours, experiences of basic psychological needs satisfaction, intrinsic motivation to teach, and teaching efficacy. The findings demonstrated that this web-based need-supportive intervention programme for PE teachers was partially effective.

First, it was hypothesized that the PE teachers in the experimental group, compared to the PE teachers in the control group, would perceive higher provision of autonomy, competence, and relatedness support at follow-up. This hypothesis was partly supported because PE teachers in the experimental group reported that they provided significantly higher autonomy support and competence support to their students after they participated in this four-week web-based need-supportive intervention programme. In other words, PE teachers reported that they offered to their students' choices and provided information on how to be more physically active (i.e., provided autonomy support), and helped their students to feel that they were competent at physical education lesson (i.e., provided competence support) after they had completed this web-based intervention programme. This finding is similar to a previous study by Tilga et al. (2021a) that a web-based intervention programme for PE teachers could have a direct effect on PE teachers self-reported autonomy support. Although the previous study based on students' reports has indicated that PE teachers effectively become more competence-supportive towards their students after they have completed web-based need-supportive intervention programme (Paap, et al., 2024), there are no previous studies assessing changes in provision of competence and relatedness support from the PE teacher perspective. The possible reason why PE teachers demonstrated significant gains in their self-reported provision of competence support might be related to the reason that PE teachers acquired various knowledge on how to make their students feel more competent. The possible reason why PE teachers did not demonstrate significant gains in their self-reported provision of relatedness support might be related to the reason that the provision of relatedness support also implies more specific interaction with their students which might imply that PE teachers need a longer period of time to apply provision of relatedness support. However, based on previous findings and based on students' self-reports, PE teachers might become more relatedness-supportive towards their students after they have participated in the web-based need-supportive intervention programme (Paap, et al., 2024).

Second, it was hypothesized that the PE teachers in the experimental group, compared to the PE teachers in the control group, would perceive significantly lower provision of controlling behaviours at follow-up. This hypothesis was not supported because there were no significant differences between the experimental and control group PE teachers' self-reports at follow-up on their provision of controlling behaviours to their students. The possible reason for this might be that PE teachers had to focus on mastering very many different motivational behaviours. Also, this web-based need-supportive intervention programme for PE teachers exclusively focused on increasing their autonomy, competence, and relatedness support toward their students, but there was no specific focus on how to avoid controlling behaviours towards their students. For example, in a previous study, based on students' self-reports, the intervention programme was effective in reducing the experimental group PE teachers' controlling behaviours (Tilga, et al, 2021c). Also, in this study by Tilga et al. (2021c), the focus was only on increasing autonomy support and reducing controlling behaviours towards students, which might make it easier to PE teachers to acquire new knowledge. Previous studies have also indicated that it is important to not only increase the autonomy support, but also reduce the experiences of controlling behaviours because autonomy support and controlling behaviours are related to students' outcomes via separate pathways (Haerens, et al., 2015; Tilga, et al., 2020a).

Third, it was hypothesized that the PE teachers in the experimental group, compared to the PE teachers in the control group, would perceive their own psychological needs higher satisfaction at follow-up. This hypothesis was not supported because there were no significant differences between the experimental and control group PE teachers' self-reports in their own basic psychological need satisfaction at follow-up. The possible reason for this might be that it takes more time for PE teachers before they experience gains in their own basic psychological needs satisfaction when providing need support to their students. This finding is similar to previous research by Tilga et al. (2021a), in which there was no direct effect from web-based intervention on PE teachers own basic psychological need satisfaction. However, in a study by Cheon et al. (2014), teachers reported higher psychological need satisfaction after they completed autonomy-supportive intervention programme. The possible reason for this might be that face-to-face intervention programme by Cheon et al. (2014) enabled to provide more personal approach to teachers that might help in inducing teachers experiences of psychological need satisfaction compared to web-based intervention programme. However, previous studies have demonstrated that the greatest intervention effects might be found when face-to-face and web-based intervention programmes are combined (Tilga, et al., 2021c).

Fourth, it was hypothesized that the PE teachers in the experimental group, compared to the PE teachers in the control group, would experience higher intrinsic motivation to teach at follow-up. This hypothesis was not supported because there were no significant differences between the experimental and control group PE teachers' perceptions of intrinsic motivation to teach at follow-up. This finding is similar to a study by Tilga et al. (2021a), in which web-based intervention had no direct effect on PE teachers' intrinsic motivation. The possible reason for this might be that intrinsic reasons to teach take time to consolidate. It might be that PE teachers need more time to professionalize these need-supportive behaviours before they experience greater intrinsic motivation to teach their students. However, in a study by Cheon et al. (2014), teachers experienced higher intrinsic motivation to teach after they have completed face-to-face autonomy-supportive intervention programme. The possible reason for this might be that focusing exclusively on autonomy support behaviours might enable greater opportunities to experience gains in intrinsic motivation to teach. Previous research has clearly shown that perceived autonomy support is exclusively related to experiences of intrinsic motivation (e.g., Kalajas-Tilga, et al., 2020). Another reason might be that face-to-face approach by Cheon et al. (2014) enabled more personalized approach to induce intrinsic motivation in teachers. However, based on previous research (Tilga, et al., 2021c), the greatest intervention effects might occur to combine face-to-face and web-based approaches in delivering knowledge about need-supportive behaviours to PE teachers.

Fifth, it was hypothesized that the PE teachers in the experimental group, compared to the PE teachers in the control group, would experience higher teaching efficacy at follow-up. This hypothesis was supported because there were significant differences between the experimental and control group experiences of teaching efficacy at follow-up. More specifically, after completing the intervention programme, the PE teachers in the experimental group reported significant gains in their teaching efficacy at follow-up compared to those PE teachers who were in the control group. This finding is similar to a study by Cheon et al. (2014), in which intervention group teachers exhibited significant gains in their teaching efficacy compared to the control group at follow-up. The possible reason for this finding is that PE teachers used strategies to provide need support to their students that resulted in their more effective teaching.

The main findings of the study indicate that the web-based need-supportive intervention programme for PE teachers was partially effective. The PE teachers who participated in the intervention reported significantly higher provision of autonomy support and competence support to their students, aligning with previous research by Tilga et al. (2021a) and Paap et al. (2024), which also found enhancements in these areas following similar interventions. However, the intervention did not lead to significant gains in the provision of relatedness support, suggesting that this aspect may require more time or specific strategies to implement effectively—a point not extensively addressed in earlier studies. Additionally, there were no significant reductions in controlling behaviours, possibly because the programme did not specifically focus on reducing these behaviours, contrasting with studies like Tilga et al. (2021c) that did address such reductions when targeting controlling practices. The intervention also did not result in significant improvements in PE teachers' own psychological need satisfaction or intrinsic motivation to teach, mirroring findings from Tilga et al. (2021a) but differing from Cheon et al. (2014), where face-to-face interventions yielded positive results in these areas. This suggests that the mode of delivery may influence the effectiveness of interventions on teachers' internal experiences. Notably, the study found significant gains in teaching efficacy among the experimental group, consistent with Cheon et al. (2014), indicating that need-supportive interventions can enhance teachers' confidence in their teaching abilities.

Practical implications

The findings from this study offer several practical implications for PE teacher training. The web-based need-supportive intervention programme was effective in enhancing teachers' autonomy and competence support, as well as their overall teaching efficacy. Based on these results, PE teachers are encouraged to adopt autonomy-supportive strategies, such as providing students with choice, using non-controlling language, and encouraging self-initiated behaviour, which are likely to promote students' intrinsic motivation and engagement in PE classes. Similarly, competence-supportive practices, like setting optimal challenges and offering constructive feedback, may enhance students' sense of competence and engagement.

Additionally, while the decrease in teachers' controlling behaviours was not statistically significant when compared with the control group, the trend observed in reduced controlling behaviours post-intervention is noteworthy. This slight decrease suggests that implementing need-supportive strategies may contribute to a natural reduction in controlling behaviours, even if the primary focus is on fostering autonomy and competence. As controlling behaviours can detract from students' motivational experiences, teachers are encouraged to reflect on their practices and gradually incorporate strategies that minimize controlling interactions. By reducing these behaviours, teachers may foster a more positive and autonomy-supportive classroom environment, aligning with the broader objectives of SDT to promote motivation and well-being.

Looking ahead, web-based interventions hold substantial promise for advancing PE teacher training and professional development. Given the convenience, accessibility, and scalability of online platforms, web-based programmes can reach a larger population of educators than traditional face-to-face workshops. This is especially relevant in PE, where teachers often have limited time and resources for continuous professional development. Web-based interventions also provide a flexible learning environment that allows teachers to engage with training content at their own pace, revisit materials as needed and apply newly learned strategies directly to their practice. Additionally, as demonstrated in this study, web-based formats can successfully promote need-supportive behaviours, which are critical for fostering students' motivation and positive experiences in PE classes. As digital technology continues to evolve, there is potential to enhance these interventions further with interactive elements, peer collaboration, and personalized feedback. This could deepen the impact of training programmes by allowing teachers to receive more tailored support and guidance. Future research should continue to explore and refine web-based approaches, particularly focusing on how they can sustain long-term improvements in teaching efficacy and classroom climate in PE settings. Highlighting the potential of these digital interventions offers exciting prospects for scalable, high-impact teacher development that aligns with the broader educational goals of promoting physical activity, motivation, and well-being in students.

Limitations and future directions

Although there are several strengths of this study, there are also several limitations related to this study that should be acknowledged. First, in this study we relied on teachers' self-reported measures to examine intervention effects. However, there might be great differences between self-reports and actual behaviour (Aguado-Gómez, Diaz-Cueto, Hernández-Álvarez, & López-Rodríguez, 2016). Future studies would do well by videotaping PE lessons to capture actual changes in PE teachers' behaviours or PE lessons could be observed and rated by external observers (Aelterman, Vansteenkiste, Van Keer, & Haerens, 2016). Second, in this study, PE teachers' data of only one-month follow-up was examined. Based on previous studies, one-month follow-up data might demonstrate changes in most study variables among experimental group (e.g., Tilga, Hein, & Koka, 2019a), but 15-month of follow-up data might reveal fewer enduring effects on the study variables (Tilga, Kalajas-Tilga, Hein, Raudsepp, & Koka, 2020b). Future studies are recommended to test intervention effects based on longer follow-up period. Third, in this study perceptions of controlling behaviours were measured via experiences of negative conditional regard, controlling use of grades, and intimidation (Hein, et al., 2015). In a recent study by De Meyer, Soenens, Aelterman, De Bourdeaudhuij, and Haerens (2016), framework of externally and internally controlling teaching behaviours was proposed and a scale to measure faces of PE teachers' behaviours was developed and validated (Burgueño, Abós, García-González, Tilga, & Sevil-Serrano, 2021). Future research could test changes in different dimensions of controlling behaviours such as externally and internally controlling teaching as promising predictors of basic psychological need satisfaction and frustration (Burgueño, et al., 2021, Koka, Tilga, Hein, Kalajas-Tilga, & Raudsepp, 2021, Viksi & Tilga, 2022). Fourth, in this study, autonomy support was considered as a unidimensional construct. Previous studies have demonstrated that multidimensional approach to autonomy-supportive behaviour (Tilga, Hein, & Koka, 2017) enables to describe a larger amount of variance in motivational outcomes (Zimmermann, Tilga, Bachner, & Demetriou, 2020, 2021). Thus, future studies could adopt a multidimensional approach to measure autonomy support from PE teachers. Fifth, perceived structure and chaos from the circumplex model (Aelterman, et al., 2019), were not measured in this study. Recent research has demonstrated that perceived structure and chaos are important predictors of motivational outcomes in the field of PE (Diloy-Peña et al., 2024; Tilga, Vahtra, & Koka, 2023). Future research could do well by adopting scales to measure constructs from the circumplex model. Sixth, in this study we relied on a classification system of motivational behaviours proposed by Teixeira and colleagues (2020). However, classification system of motivational behaviours proposed by Teixeira and colleagues (2020) is more relevant to health context. In a recent study by Ahmadi and colleagues (2023), a classification system for teachers' motivational behaviours recommended in self-determination theory interventions for educational context was developed. Also, classification system developed by Ahmadi et al. (2023) also provides a list of need-thwarting behaviours that should be avoided. It is important to not only teach how to provide need support, but also to provide information on how to avoid need thwarting because controlling behaviours dampen the effect of need support (Tilga, Hein, Koka, Hamilton, & Hagger, 2019b), and need satisfaction and need thwarting are related to respective outcomes via separate pathways (Haerens, et al, 2015; Tilga, et al., 2020c). Future studies that rely on Ahmadi and colleagues' (2023) classification system could do well by developing intervention programme for teachers to enhance their motivational behaviours.

In conclusion, the current study provides initial information that our developed web-based need-supportive intervention programme for PE teachers is effective to increase their self-reported autonomy support, competence support and teaching efficacy. Thus, teachers are recommended to study specific motivational behaviours proposed by Teixeira and colleagues (2020), if the aim is to increase teachers' perceptions of their autonomy support, competence support and teaching efficacy towards their students.

References

Aelterman, N., Vansteenkiste, M., Van Keer, H., & Haerens, L. (2016). Changing teachers' beliefs regarding autonomy support and structure: The role of experienced psychological need satisfaction in teacher training. *Psychology of Sport and Exercise 23*, 64-72. https://doi.org/10.1016/j.psychsport.2015.10.007

Aelterman, N., Vansteenkiste, M., Haerens, L., Soenens, B., Fontaine, J.R.J., & Reeve, J. (2019). Toward an integrative and fine-grained insight in motivating and demotivating teaching styles: The merits of a circumplex approach. *Journal of Educational Psychology, 111*(3), 497-521. https://doi.org/10.1037/edu0000293

Aguado-Gómez, R., Diaz-Cueto, M., Hernández-Álvarez, J.L., & López-Rodríguez, Á. (2016). Supporting autonomy in physical education: Perception versus reality. *Revista Internacional de Medicina y Ciencias de La Actividad Física y El Deporte, 16*, 183-202. https://doi.org/10.15366/rimcafd2016.62.001

Ahmadi, A., Noetel, M., Parker, P., Ryan, R.M., Ntoumanis, N., Reeve, J., Beauchamp, M., Dicke, T., Yeung, A., Ahmadi, M., Bartholomew, K., Chiu, T.K.F., Curran, T., Erturan, G., Flunger, B., Frederick, C., Froiland, J.M., González-Cutre, D., Haerens, L., . . ., & Lonsdale, C. (2023). A classification system for teachers' motivational behaviors recommended in self-determination theory interventions. *Journal of Educational Psychology, 115*(8), 1158-1176. https://doi.org/10.1037/edu0000783

Bartholomew, K. J., Ntoumanis, N., & Thøgersen-Ntoumani, C. (2010). The controlling interpersonal style in a coaching context: Development and initial validation of a psychometric scale. *Journal of Sport and Exercise Psychology, 32*(2), 193-216. https://doi.org/10.1123/jsep.32.2.193

Burgueño, R., Abós, Á., García-González, L., Tilga, H., & Sevil-Serrano, J. (2021). Evaluating the psychometric properties of a scale to measure perceived external and internal faces of controlling teaching among students in physical education. *International Journal of Environmental Research and Public Health, 18*(1), 298. https://doi.org/10.3390/ijerph18010298

Byrne, B.M. (2010). *Structural equation modeling with AMOS: Basic concepts, applications, and programming* (2nd ed.). Routledge/Taylor & Francis Group.

Chen, B., Vansteenkiste, M., Beyers, W., Boone, L., Deci, E.L., Van der Kaap-Deeder, J., Duriez, B., Lens, W., Matos, L., Mouratidis, A., Ryan, R.M., Sheldon, K.M., Soenens, B., Van Petegem, S., & Verstuyf, J. (2015). Basic psychological need satisfaction, need frustration, and need strength across four cultures. *Motivation and Emotion, 39*(2), 216-236. https://doi.org/10.1007/s11031-014-9450-1

Cheon, S.H., Reeve, J., Yu, T.H., & Jang, H.R. (2014). The teacher benefits from giving autonomy support during physical education instruction. *Journal of Sport and Exercise Psychology, 36*(4), 331-346. https://doi.org/10.1123/jsep.2013-0231

De Meyer, J., Soenens, B., Aelterman, N., De Bourdeaudhuij, I., & Haerens, L. (2016). The different faces of controlling teaching: Implications of a distinction between externally and internally controlling teaching for students' motivation in physical education. *Physical Education and Sport Pedagogy, 21*(6), 632-652. https://doi.org/10.1080/17408989.2015.1112777

Diloy-Peña, S., García-González, L., Burgueño, R., Tilga, H., Koka, A., & Abós, Á. (2024). A cross-cultural examination of the role of (de-)motivating teaching styles in predicting students' basic psychological needs in physical education: A circumplex approach. *Journal of Teaching in Physical Education*, ahead of print. https://doi.org/10.1123/jtpe.2023-0036

Goudas, M., Biddle, S., & Fox, K. (1994). Perceived locus of causality, goal orientations, and perceived competence in school physical education classes. *The British Journal of Educational Psychology, 64*(3), 453-463. https://doi.org/10.1111/j.2044-8279.1994.tb01116.x

Haerens, L., Aelterman, N., Vansteenkiste, M., Soenens, B., & Van Petegem, S. (2015). Do perceived autonomy-supportive and controlling teaching relate to physical education students' motivational experiences through unique pathways? Distinguishing between the bright and dark side of motivation. *Psychology of Sport and Exercise, 16*, 26-36. https://doi.org/10.1016/j.psychsport.2014.08.013

Hagger, M.S., Chatzisarantis, N.L.D., Hein, V., Pihu, M., Soós, I., & Karsai, I. (2007). The Perceived Autonomy Support Scale for Exercise Settings (PASSES): Development, validity, and cross-cultural invariance in young people. *Psychology of Sport and Exercise, 8*(5), 632-653. https://doi.org/10.1016/j.psychsport.2006.09.001

Hein, V., Koka, A., & Hagger, M.S. (2015). Relationships between perceived teachers' controlling behaviour, psychological need thwarting, anger and bullying behaviour in high-school students. *Journal of Adolescence, 42*, 103-114. https://doi.org/10.1016/j.adolescence.2015.04.003

Hu, L.-T., & Bentler, P.M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55. https://doi.org/10.1080/10705519909540118

Jang, H., Kim, E.J., & Reeve, J. (2012). Longitudinal test of self-determination theory's motivation mediation model in a naturally occurring classroom context. *Journal of Educational Psychology, 104*(4), 1175-1188. https://doi.org/10.1037/a0028089

Kalajas-Tilga, H., Koka, A., Hein, V., Tilga, H., & Raudsepp, L. (2020). Motivational processes in physical education and objectively measured physical activity among adolescents. *Journal of Sport and Health Science, 9*(5), 462-471. https://doi.org/10.1016/j.jshs.2019.06.001

Kalajas-Tilga, H., Hein, V., Koka, A., Tilga, H., Raudsepp, L., & Hagger, M.S. (2022a). Application of the trans-contextual model to predict change in leisure time physical activity. *Psychology and Health, 37*(1), 62-86. https://doi.org/10.1080/08870446.2020.1869741

Kalajas-Tilga, H., Hein, V., Koka, A., Tilga, H., Raudsepp, L., & Hagger, M.S. (2022b). Trans-contextual model predicting change in out-of-school physical activity: A one-year longitudinal study. *European Physical Education Review, 28*(2), 463-481. https://doi.org/10.1177/1356336X211053807

Koka, A., Tilga, H., Kalajas-Tilga, H., Hein, V., & Raudsepp, L. (2019). Perceived controlling behaviors of physical education teachers and objectively measured leisure-time physical activity in adolescents. *International Journal of Environmental Research and Public Health, 16*(15), 2709. https://doi.org/10.3390/ijerph16152709

Koka, A., Tilga, H., Kalajas-Tilga, H., Hein, V., & Raudsepp, L. (2020). Detrimental effect of perceived controlling behavior from physical education teachers on students' leisure-time physical activity intentions and behavior: An application of the trans-contextual model. *International Journal of Environmental Research and Public Health, 17*(16), 5939. https://doi.org/10.3390/ijerph17165939

Koka, A., Tilga, H., Hein, V., Kalajas-Tilga, H., & Raudsepp, L. (2021). A multidimensional approach to perceived teachers' autonomy support and its relationship with intrinsic motivation of students in physical education. *International Journal of Sport Psychology, 52*(3), 266-286. https://doi.org/10.7352/IJSP.2021.52.2

Meerits, P.-R., Tilga, H., & Koka, A. (2022). Fostering need-supportive behaviors in physical education teachers and parents: A cluster randomized controlled trial study protocol of a web-based intervention on secondary school students' physical activity. *Methods and Protocols*, *5*(5), 83. https://doi.org/10.3390/mps5050083

Meerits, P.-R., Tilga, H., & Koka, A. (2023). Web-based need-supportive parenting program to promote physical activity in secondary school students: A randomized controlled pilot trial. *BMC Public Health, 23*(1), 1627. https://doi.org/10.1186/s12889-023-16528-4

Murray, E. (2012). Web-based interventions for behavior change and self-management: Potential, pitfalls, and progress. *Medicine 2.0, 1*(2), e3. https://doi.org/10.2196/med20.1741

Nunnally, J.C. (1978). *Psychometric theory* (2nd ed.). New York: McGraw-Hill.

Paap, H., Koka, A., Meerits, P., & Tilga, H. (2024). The effectiveness of web-based need-supportive intervention program for physical education teachers on students' physical activity-related cognitive and behavioural outcomes. https://doi.org/10.31234/osf.io/v98sc

Pelletier, L.G., Séguin-Lévesque, C., & Legault, L. (2002). Pressure from above and pressure from below as determinants of teachers' motivation and teaching behaviors. *Journal of Educational Psychology, 94*(1), 186-196. https://doi.org/10.1037/0022-0663.94.1.186

Raabe, J., Schmidt, K., Carl, J., & Höner, O. (2019). The effectiveness of autonomy support interventions with physical education teachers and youth sport coaches: A systematic review. *Journal of Sport and Exercise Psychology, 41*(6), 345-355. https://doi.org/10.1123/jsep.2019-0026

Reeve, J. (2013). How students create motivationally supportive learning environments for themselves: The concept of agentic engagement. *Journal of Educational Psychology, 105*(3), 579-595. https://doi.org/10.1037/a0032690

Roth, G., Assor, A., Kanat-Maymon, Y., & Kaplan, H. (2007). Autonomous motivation for teaching: How self-determined teaching may lead to self-determined learning. *Journal of Educational Psychology, 99*(4), 761-774. https://doi.org/10.1037/0022-0663.99.4.761

Ryan, R.M., & Deci, E.L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology, 61*, 101860. https://doi.org/10.1016/j.cedpsych.2020.101860

Standage, M., Duda, J.L., & Ntoumanis, N. (2005). A test of self-determination theory in school physical education. *The British Journal of Educational Psychology, 75*(3), 411-433. https://doi.org/10.1348/000709904X22359

Stebbings, J., Taylor, I.M., Spray, C.M., & Ntoumanis, N. (2012). Antecedents of perceived coach interpersonal behaviors: The coaching environment and coach psychological well- and ill-being. *Journal of Sport and Exercise Psychology, 34*(4), 481-502. https://doi.org/10.1123/jsep.34.4.481

Su, Y.-L., & Reeve, J. (2011). A meta-analysis of the effectiveness of intervention programs designed to support autonomy. *Educational Psychology Review, 23*(1), 159-188. https://doi.org/10.1007/s10648-010-9142-7

Taylor, I.M., Ntoumanis, N., & Standage, M. (2008). A self-determination theory approach to understanding the antecedents of teachers' motivational strategies in physical education. *Journal of Sport and Exercise Psychology, 30*(1), 75-94. https://doi.org/10.1123/jsep.30.1.75

Teixeira, P.J., Marques, M.M., Silva, M.N., Brunet, J., Duda, J.L., Haerens, L., La Guardia, J., Lindwall, M., Lonsdale, C., Markland, D., Michie, S., Moller, A.C., Ntoumanis, N., Patrick, H., Reeve, J., Ryan, R.M., Sebire, S.J., Standage, M., Vansteenkiste, M., . . ., & Hagger, M.S. (2020). A classification of motivation and behavior change techniques used in self-determination theory-based interventions in health contexts. *Motivation Science, 6*(4), 438-455. https://doi.org/10.1037/mot0000172

Tilga, H., Hein, V., & Koka, A. (2017). Measuring the perception of the teachers' autonomy-supportive behavior in physical education: Development and initial validation of a multi-dimensional instrument. *Measurement in Physical Education and Exercise Science, 21*(4), 244-255. https://doi.org/10.1080/1091367X.2017.1354296

Tilga, H., Hein, V., & Koka, A. (2019a). Effects of a web-based intervention for PE teachers on students' perceptions of teacher behaviors, psychological needs, and intrinsic motivation. *Perceptual and Motor Skills, 126*(3), 559-580. https://doi.org/10.1177/0031512519840150

Tilga, H., Hein, V., Koka, A., Hamilton, K., & Hagger, M.S. (2019b). The role of teachers' controlling behaviour in physical education on adolescents' health-related quality of life: Test of a Conditional Process Model*. *Educational Psychology, 39*(7), 862-880. https://doi.org/10.1080/01443410.2018.1546830

Tilga, H., Kalajas-Tilga, H., Hein, V., Raudsepp, L., & Koka, A. (2020a). How does perceived autonomy-supportive and controlling behaviour in physical education relate to adolescents' leisure-time physical activity participation? *Kinesiology, 52*(2), 265-272. https://doi.org/10.26582/k.52.2.13

Tilga, H., Kalajas-Tilga, H., Hein, V., Raudsepp, L., & Koka, A. (2020b). 15-month follow-up data on the web-based autonomy-supportive intervention program for PE teachers. *Perceptual and Motor Skills, 127*(1), 5-7. https://doi.org/10.1177/0031512519870914

Tilga, H., Hein, V., Koka, A., & Hagger, M.S. (2020c). How physical education teachers' interpersonal behaviour is related to students' health-related quality of life. *Scandinavian Journal of Educational Research, 64*(5), 661–676. https://doi.org/10.1080/00313831.2019.1595718

Tilga, H., Kalajas-Tilga, H., Hein, V., Raudsepp, L., & Koka, A. (2021a). Effects of a web-based autonomy-supportive intervention on physical education teacher outcomes. *Education Sciences, 11*(7), 316. https://doi.org/10.3390/educsci11070316

Tilga, H., Kalajas-Tilga, H., Hein, V., Raudsepp, L., & Koka, A. (2021b). Perceived autonomy support from peers, parents, and physical education teachers as predictors of physical activity and health-related quality of life among adolescents—A one-year longitudinal study. *Education Sciences, 11*(9), 457. https://doi.org/10.3390/educsci11090457

Tilga, H., Kalajas-Tilga, H., Hein, V., & Koka, A. (2021c). Web-based and face-to-face autonomy-supportive intervention for physical education teachers and students' experiences. *Journal of Sports Science and Medicine, 20*(4), 672-683. https://doi.org/10.52082/jssm.2021.672

Tilga, H., Vahtra, K., & Koka, A. (2023). The role of teachers (de-)motivational styles on students' autonomous motivation in physical education and leisure time. *Baltic Journal of Health and Physical Activity, 15*(4), 5. https://doi.org/10.29359/BJHPA.15.4.05

Tschannen-Moran, M., & Hoy, A.W. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education, 17*(7), 783-805. https://doi.org/10.1016/S0742-051X(01)00036-1

Vasconcellos, D., Parker, P.D., Hilland, T., Cinelli, R., Owen, K.B., Kapsal, N., Lee, J., Antczak, D., Ntoumanis, N., Ryan, R.M., & Lonsdale, C. (2020). Self-determination theory applied to physical education: A systematic review and meta-analysis. *Journal of Educational Psychology, 112*(7), 1444-1469. https://doi.org/10.1037/edu0000420

Viira, R., & Koka, A. (2012). Participation in afterschool sport: Relationship to perceived need support, need satisfaction, and motivation in physical education. *Kinesiology, 44*(2), 199-208.

Viksi, A., & Tilga, H. (2022). Perceived physical education teachers' controlling behaviour and students' physical activity during leisure time—The dark side of the trans-contextual model of motivation. *Behavioral Sciences, 12*(9), 342. https://doi.org/10.3390/bs12090342

White, R.L., Bennie, A., Vasconcellos, D., Cinelli, R., Hilland, T., Owen, K.B., & Lonsdale, C. (2021). Self-determination theory in physical education: A systematic review of qualitative studies. *Teaching and Teacher Education, 99*, 103247. https://doi.org/10.1016/j.tate.2020.103247

Zimmermann, J., Tilga, H., Bachner, J., & Demetriou, Y. (2020). The German multi-dimensional perceived autonomy support scale for physical education: Adaption and validation in a sample of lower track secondary school students. *International Journal of Environmental Research and Public Health, 17*(19), 7353. https://doi.org/10.3390/ijerph17197353

Zimmermann, J., Tilga, H., Bachner, J., & Demetriou, Y. (2021). The effect of teacher autonomy support on leisure-time physical activity via cognitive appraisals and achievement emotions: A mediation analysis based on the control-value theory. *International Journal of Environmental Research and Public Health, 18*(8), 3987. https://doi.org/10.3390/ijerph18083987

Submitted: February 18, 2024
Accepted: November 25, 2024
Published Online First: December 16, 2024

Correspondence to:
Henri Tilga, Ph.D.
Address: 4 Ujula Street, EE 51008, Tartu, Estonia
Phone: +372 53 818 440
E-mail: henri.tilga@ut.ee

VALIDITY AND RELIABILITY OF THE INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE-SHORT FORM IN ADOLESCENTS

Dragan Djurdjević[1], Jovana Todorović[2], and Sandra Sipetic-Grujičić[3]

[1]Department of Sports Medicine, Faculty of Medicine, University of Belgrade, Serbia
[2]Institute of Social Medicine, Faculty of Medicine, University of Belgrade, Serbia
[3]Institute of Epidemiology, Faculty of Medicine, University of Belgrade, Serbia

Original scientific paper
DOI 10.26582/k.56.2.10

Abstract:

A very few studies examined the validity and reliability of the International Physical Activity Questionnaire-Short Form (IPAQ-SF) in the adolescent population**,** and no study has been conducted in Serbia. The aim of this study was to examine the validity and reliability of the IPAQ-SF in adolescents. The cross-sectional study included 101 adolescents aged 15-19 years (31.8% boys, 68.2% girls). The study instrument was a questionnaire regarding demographic characteristics, physical activity, and iPhone built-in pedometer. The data were analyzed using the interclass correlation coefficient (ICC), Spearman correlation coefficient, exploratory factor analysis (EFA) with promax rotation, and two confirmatory factor analyses (CFA) to examine theoretical factor model and for the two-factor model based on the EFA. Total activity measured by IPAQ-SF correlated weakly but significantly with the pedometer measured steps (r=0.25, p=.045). The EFA showed two factors that explained 64.19% of the variance (46.15% and 18.05%). The CFA for the two-factor model showed acceptable fit, and for the three-factor model better fit GFI 0.951, AGFI 0.827, CFI 0.934, RMSEA 0.131 (95% CI: 0.07-0.198). Poor to moderate reliability was observed with ICC (0.36-0.65). Our study shows that the IPAQ-SF has a good validity and acceptable reliability in the population of adolescence, and has numerous advantages, especially in the population studies, but it requires caution in the interpretation of the results.

Key words: *IPAQ-SF, physical activity, adolescents, iPhone Health App, pedometer, validity*

Introduction

Regular physical activity (PA) has many health benefits. PA has a preventive effect on chronic non-communicable diseases, such as cardiovascular diseases, hypertension, type 2 diabetes mellitus, obesity, cancer, and metabolic syndrome (Bhatt, 2016; Lavie, Ozemek, Carbone, Katzmarzyk, & Blair, 2019). It has a positive effect on social and psychological status, improves the quality of life, and reduces costs of the healthcare (Wang, et al., 2023). Insufficient PA is associated with 20-30% increased risk of all-cause mortality (WHO, 2022). Older adolescents (18-19 years old) are less physically active than younger ones (15-16 years old) (Djurdjevic, Nikolic, Mazic, & Sipetic-Grujicic, 2023). Adolescents with obesity have an increased risk of being obese in adulthood, and a higher risk of developing chronic non-communicable diseases. In addition, insufficient PA during adolescence is associated with the development of depression and destructive behavior, poorer social life and school success (Asigbee, Whitney, & Peterson, 2018).

According to the World Health Organization (WHO) and the National Health Service (NHS), the recommended daily PA for adolescents is 60 minutes of moderate to vigorous PA together with exercises to strengthen the musculoskeletal system at least three times a week, and flexibility exercises at least twice a week (NHS, 2019; WHO, 2020). WHO data show that about 80% of adolescents do not meet the recommendations for PA (WHO, 2020).

Researchers and health care professionals need accurate data on PA in order to better understand PA behavior and develop programmes for the improvement of PA levels in this population. To obtain accurate data, it is necessary to use a valid instrument. PA can be measured objectively and subjectively. Among the objective measures of PA, the most commonly used instruments are accelerometers and pedometers (Ramakrishnan, et al., 2021). Among subjective measures of PA, the most commonly used instruments are questionnaires (Sember, et al., 2020). Accelerometers are used as a standard in PA estimation, but due to their cost, they are not suitable for use in large-scale studies. In addition, the pedometer is a valid instrument for community based studies, cheaper than an accelerometer, easier to use, but has limitations in measuring slow walking (<0.6m/s), in swimming, cycling, for people with abnormal gait patterns, and people who are obese (Ehrler, Weber, & Lovis, 2016; Keating, et al., 2019).

The technological development and the increasing possibilities provided by smartphones have made it easier to monitor PA and health behavior. In 2023, 6.92 billion (86.29%) of the world's population used smartphones (Bankmycell, 2023). In addition to the usual features, smartphones have a built-in gyroscope, compass and triaxial accelerometer, with very similar specifications to the accelerometers used in PA monitoring (Romeo, et al., 2019). Modern iPhone models, starting in 2013 and iPhone 5s model, unlike other smartphone manufacturers have a built-in M (motion) coprocessor, which is responsible for processing data related to PA (Apple, 2013). Some studies have shown that just having the pedometer app increases the total number of steps taken (Romeo, et al., 2019; Sullivan & Lachman, 2017). To monitor and encourage PA, Apple has developed the Health App. Due to these hardware and software characteristics, it is possible to monitor movement, energy consumption, intensity, number of steps, elevation, sleep, etc. All this makes the iPhone a valid and reliable instrument, which can be used as a valid replacement for the pedometer and accelerometer (Höchsmann, et al., 2018; Major & Alford, 2016; Nolan, Mitchell, & Doyle-Baker, 2014).

Many researchers opt for using questionnaires over the objective measures as they are easy to use, and the studies are of lower cost. Among the questionnaires developed so far for the measurement of PA, the most commonly used is the International Physical Activity Questionnaire-Short Form (IPAQ-SF). In some studies, this method has been shown to be less accurate due to its self-reported nature, language-specificity, susceptibility to bias and most often overestimation of PA (Fillon, et al., 2022; Rääsk, et al., 2017). Validity and reliability of the IPAQ-SF has been verified in many studies in the adult population (Sember, et al., 2020). However, validity and reliability of the IPAQ-SF in adolescents is less known. To the best of our knowledge, only four studies examined the validity and reliability of the IPAQ-SF in this population, i.e., investigating participants that in some part belonged to the age of high school students aged 15-19 years (Lachat et al., 2008; Monyeki, Moss, Kemper, & Twisk, 2018; Rangul, Holmen, Kurtze, Cuypers, & Midthjell, 2008; Wang, Chen, & Zhuang, 2013), and no study has been conducted in Serbia.

The aim of this study was to examine the validity and reliability of the IPAQ-SF in adolescents 15-19 years old for the measurement of PA, and to compare the results from IPAQ-SF with the number of steps measured by an iPhone smartphone recorded in the Health App.

Methods

A total of 101 adolescents (36 boys, 65 girls), 15-19 years old, were included in the study conducted during January 2020. The research targeted students from two high schools in Valjevo, a key administrative hub of the Kolubara district in western Serbia. Specifically, students from Valjevo High School and the Medical School were considered for participation. To be eligible, students needed to meet two requirements: they had to be present at school during the designated recruitment week and possess an iPhone. Only those who met these criteria were contacted and invited to participate in the study. Targeting Valjevo High School and the Medical School allowed researchers to work with a practical and manageable sample that is likely representative of students in the Kolubara district. These schools' curricula emphasize physical activity and healthcare, which may enhance students' interest and engagement in the study, unlike other vocational schools, thereby potentially improving the quality of the data collected. Participants who lacked one or more values, or who answered "I don't know," were excluded from the analysis. The analysis included only participants with the complete data, and our final sample included 66 participants.

Information about the study and the study protocol were submitted to the School Board and then to the Parents Council, who approved the research, after which the parents gave their consent for the children's participation in the study. This study was approved by the Ethical Committee of the Faculty of Medicine, University of Belgrade (No: 29/XII-18).

Data collection

The data were collected through the questionnaire which consisted of two sections: demographic characteristics (gender, age, school, grade, housing), and current physical activity level (IPAQ-SF). The data from the iPhone Health App, as a pedometer, was recorded along with the anthropometric measures (height, weight, waist circumference).

IPAQ-SF

The assessment of PA was done through the modified and translated Serbian version of IPAQ-SF. Modification and translation were done in three phases: backward translation, forward translation and pilot testing (kappa ≥ 0.90) (Todorovic, et al., 2019). IPAQ-SF consists of seven questions through which the level of physical activity and sitting time in the previous seven days are assessed. Participants were asked to record how many days a week they engage in PA (vigorous PA, moderate PA, walking) and how many hours and minutes, as well as how much time they spend sitting. All data from the survey were processed in order to calculate energy expenditure expressed in MET-min/week (Harraqui, et al., 2023). Only those activities that lasted at least 10 minutes were considered. Energy expenditure (in MET minutes per week) was calculated as a sum of energy expenditure in all activities (in MET-min/week in each of the activities—vigorous PA [VPA], moderate PA [MPA] and walking). The energy expenditure in each of the activities was calculated as number of days of activity*number of minutes/day of activity*k. K values used were the values recommended for IPAQ scoring: 3.3 METs for walking, 4 METs for moderate activity, and 8 METs for vigorous activity (Harraqui, et al., 2023).

iPhone Health App (pedometer)

Using the iPhone, built-in triaxial accelerometer and motion co-processor in the phone, the number of steps taken was recorded through the Health App system application. As there is no manufacturer's recommendation on the specific location of the iPhone to be worn while moving, we used finding from the study by Hochsmann et al. (2018) showing that the position of the phone does not affect the accuracy of the step measurement. All participants were told to keep their phone in their trousers pocket when moving, being the most common place to carry a phone. It was emphasized to them that they should carry the phone every time they moved. The reliability and validity of the iPhone in measuring steps taken has been tested in the population (Case, et al., 2015; Höchsmann, et al., 2018; Nolan, et al., 2014), so it was chosen for its practical use to estimate the number of steps.

Anthropometric measurements

Body height was measured with an accuracy of 0.1 cm using an altimeter SECA 213 (Seca GmbH &Co.KG.), and body mass with an accuracy of 0.1 kg using Tanita smart scale RD-953 (Tanita Corporation, Japan). Waist circumference was measured with a measuring tape (cm) in the middle between the lower rib arch and the iliac bone. Participants were barefoot and in sportswear. After measuring height, weight and waist circumference, body mass index (BMI) (kg/m^2) was calculated as the ratio of weight (kg) and square of height (m^2). Also, WHtR was calculated as the ratio of waist circumference (cm) and height (cm).

Data analysis

Descriptive statistics are expressed as mean±SD and percentages. Student's independent t-test was used to assess differences between the normally distributed continuous variables. The differences between the continuous variables without normal distribution were assessed using Mann-Whitney U test. Chi-square was used for categorical variables. The interclass correlation coefficient (ICC) was used to assess the test-retest reliability of the IPAQ-SF. Spearman correlation coefficients were used to assess the correlation of the IPAQ-SF data (MET-min·wk^{-1}) and the steps taken by the iPhone Health App. Exploratory factor analysis (EFA) with promax rotation was done to explore the factor structure based on the original construct. Two confirmatory factor analyses (CFA) were done. The first was to examine the theoretical factor model with three scales of IPAQ-SF. The second was for the two-factor model based on the exploratory factor analysis. Confirmatory factor analyses were done using AMOS 22 (IBM Corp). Data analysis was done using IBM SPSS Statistics analysis software (v.22.0 for Mac, Chicago, IL, USA).

Results

The participants were mostly girls (68.2%). There were no significant differences between the sexes in age, participation in relation to school, school grade and housing. Girls had significantly lower BMI and WHtR (Table 1).

Measured by the IPAQ-SF, the participants had a total PA of 3526.5±2838.1 MET-min·wk^{-1}, and the number of steps taken measured with a pedometer 42,194.9±15,741.2. During physical activity, the highest energy expenditure in MET-min·wk^{-1} was during walking. Energy expenditure while walking participated with 52% of total energy expenditure (excluding sitting). After walking, the highest estimated energy expenditure was recorded during VPA, expressed in MET-min·wk^{-1}. The total number of steps per week varied between 10,930 and 74,077 (Table 2).

The EFA showed two factors that explained 64.19% of the variance. The first factor explained 46.15% of the variance and the second 18.05%.

The factor loadings for each item are presented in Table 3.

The CFA for the traditional three-factor model showed GFI 0.951, AGFI 0.827, CFI 0.934, RMSEA 0.131 (95% CI: 0.07-0.198). The CFA for the traditional three-factor model is shown in Figure 1. The CFA for the two-factor model showed that GFI was 0.895, AGFI 0.724, CFI 0.788, RMSEA 0.203 (95% CI: 0.152-0.258).

Table 4 shows the reliability of IPAQ-SF through intraclass correlation coefficient (ICC). The ICC of all domains ranged from 0.36-0.65. It was highest

Table 1. Descriptive characteristics of participants (means ± SD and percentages)

	Boys (n=21; 31.8%)	Girls (n=45; 68.2%)	p*
Age (year)	17.1 ± 1.1	16.8 ± 0.9	.21
Height (cm)	184.2 ± 5.9	167.6 ± 5.9	<.001
Weight (kg)	80.03 ± 9.5	59.6 ± 8.6	<.001
Body mass Index (kg/m^2)	23.54 ± 2.16	21.23 ± 2.83	.002
Waist circumference (cm)	88.7 ± 7.7	74.7 ± 8.6	<.001
Waist-to-height ratio	0.48 ± 0.04	0.45 ± 0.05	.007
School (%)			
Valjevo High School	71.4	64.4	.779
Medical school	28.6	35.6	
School grade[a] (%)			
1st (USA 9th)	14.3	4.4	.53
2nd (USA 10th)	4.8	33.3	
3rd (USA 11th)	42.9	37.8	
4th (USA 12th)	38.1	24.4	
Housing (%)			
Living with both parents	85.7	75.6	.573
Living with one parent	14.3	22.2	
Living with foster parents	0 (0)	2.2	

Table 2. IPAQ-SF and pedometer activity of participants (means ± SD and median)

	Boys (n=21)		Girls (n=45)		Total (N=66)		
	Mean ± SD	Median (range)	Mean ± SD	Median (range)	Mean ± SD	Median (range)	p*
IPAQ-SF (MET-min·wk^{-1})							
Vigorous activity	1557.1±1734.9	1200 (0-5040)	1069.3±1715.4	0 (0-6720)	1230.9±1724.8	160 (0-6720)	0.269
Moderate activity	637.1±805.9	360 (0-2940)	365.3±619.4	0 (0-3000)	451.8±689.8	0 (0-3000)	0.137
Walking	1923.4±1577.8	1188 (198-5544)	1806.6±1355.5	1386 (33-5544)	1843.7±1418.7	1386 (33-5544)	0.758
Sitting	3333.3±998.4	3360 (1260-5040)	3526.4±875.9	3360 (2100-5880)	3465±913.4	3360 (1260-5880)	0.428
Total activity (excluding sitting)	4137.7±3117.9	3359 (198-10371)	3241.2±2686.8	2376 (311-10932)	3526.5±2838.1	2742 (198-10932)	0.235
Pedometer (steps per week)	47536.2±13963.1	47923 (27851-74077)	39702.3±16045.4	34172 (10930-72804)	42194.9±15741.2	40416 (10930-74077)	0.059

Note. **p* values (p<.05) for comparison between genders; IPAQ-SF – International Physical Activity Questionnaire–Short Form.

Table 3. PCA with equamax rotation with the Kaiser normalization

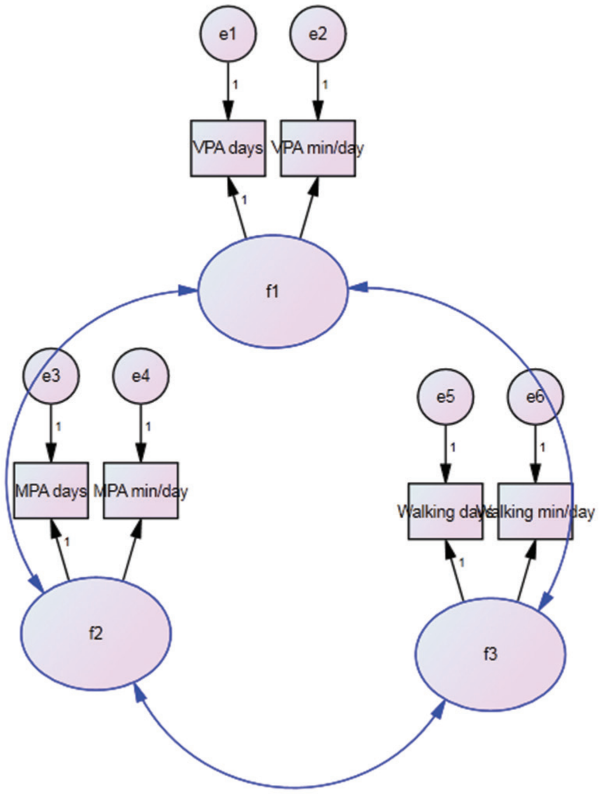
Item	Factor 1	Factor 2
Days in VPA	0.835	
Minutes/day in VPA	0.755	
Days in MPA	0.758	
Minutes/day in MPA	0.866	
Days walking		0.581
Minutes/day in walking		0.846

Note. PCA – principal component analysis.

Table 4. Test-retest reliability of the IPAQ-SF (MET-min·wk^{-1})

IPAQ-SF (MET-min·wk^{-1})	Intraclass coefficient (95% CI)	p
Vigorous activity	0.65 (0.49-0.77)	<.001
Moderate activity	0.55 (0.35-0.69)	<.001
Walking	0.36 (0.13-0.55)	.001
Sitting	0.56 (0.38-0.71)	<.001
Total activity (excluding sitting)	0.57 (0.39-0.71)	<.001

Note. IPAQ-SF – International Physical Activity Questionnaire–Short Form.



Note. CFA – confirmatory factor analysis.

Figure 1. The path diagram for the three-factor CFA.

for vigorous activity (0.65, 95% CI: 0.49-0.77) and lowest for walking (0.36, 95% CI: 0.13-0.55).

The median of PA and Spearman correlation coefficient between the IPAQ-SF (MET-min·wk^{-1}) and pedometer (steps/week) are presented in Table 5. Walking measured by the IPAQ-SF and the number of steps taken by pedometer had a relatively weak correlation, but significant ($r_s = 0.25$, p=.045). No significant correlation was found between other IPAQ-SF variables and by the pedometer measured number of steps. The correlation between energy expenditure measured by IPAQ-SF (total energy expenditure, energy expenditure in walking, energy expenditure in VPA, energy expenditure in MPA) and the number of steps/week is shown in Table 5.

Discussion and conclusions

Assessment of PA is very important in the adolescent population, as more than three-quarters of them do not meet WHO's recommendations on minimal PA (WHO, 2020). One of the most practical instruments that can be used in comprehensive studies assessing PA is the IPAQ-SF, so the aim of this study was to examine validity and reliability of the Serbian version of IPAQ-SF and to determine if there is a correlation between the subjective (IPAQ-SF) and objective measurement of PA (Health App—pedometer).

Our study showed that the average number of steps per week was just over 40,000 steps, which is almost a half of the expected number of steps for adolescents (Caillaud, et al., 2022). The recommendation by the World Health Organization for PA of adolescents states that adolescents need at least 60 minutes of moderate intensity PA each day and muscle strengthening exercises at least three times a week, which can roughly be translated in the 2,400 MET-min·wk-1 (Chaput, et al., 2020). According to our results, the average energy expenditure of participants in our study was higher than minimal recommended level. The discrepancy between the results on energy expenditure from IPAQ-SF and the number of steps per week measured by the pedometer was confirmed with the correlation analysis, as we only found significant correlation between the number of steps per week and energy expenditure from walking. The cause of this discrepancy may be in the modalities of physical activity that our participants had. The IPAQ-SF questionnaire would, unlike pedometer, measure physical activity in cycling, or swimming, and would include muscle strengthening exercises. On the other hand, IPAQ-SF was also shown to overestimate PA (Fillon, et al., 2022; Rääsk, et al., 2017), which is why we have to be very cautious when interpreting the results from it. The significant but weak correlation between the energy expenditure during walking and the number of steps per week assessed using pedometers may be due to differences in types of measurements. Pedometers assess

Table 5. Median values for IPAQ-SF and correlation between IPAQ-SF and pedometer

Variable	IPAQ-SF	Spearman correlation IPAQ-SF – pedometer (steps/week)	p*
Vigorous activity (MET-min·wk^{-1})	160	0.02	.906
Moderate activity (MET-min·wk^{-1})	0	0.12	.355
Walking (MET-min·wk^{-1})	1386	0.25[a]	**.045**
Sitting (MET-min·wk^{-1})	3360	-0.30	.810
Total activity (excluding sitting) (MET-min·wk^{-1})	2742	0.11	.378

Note. **p* values; [a]*p*<.05; IPAQ-SF – International Physical Activity Questionnaire–Short Form.

all steps, without limitation on minimal duration of activity, while we only included PA that lasted longer than ten minutes in the IPAQ-SF measurements.

The EFA showed two factors with high loadings and explained almost two-thirds of the total variance. The factors did not completely correspond to the scales in the instrument; the questions regarding walking (the number of days walking and an average number of minutes per day of walking) grouped in the separate factor, while the questions regarding VPA and MPA grouped in one factor. The questions regarding VPA and MPA always refer to the leisure time physical activity, while the questions for walking in the IPAQ-SF questionnaire do not differentiate between walking as an active form of commuting and as a form of leisure time physical activity, which may explain why the items referring to walking formed a separate factor. The CFA for the two-factor model showed an acceptable fit; however, the CFA for the traditional three-factor model showed even better fit.

In our study, the IPAQ-SF showed poor test-retest reliability for walking, while for other parameters it showed moderate reliability (Koo & Li, 2016). Nonetheless, the instrument showed good construct validity and, although some previous studies have showed that it can overestimate PA, it can be used as a reliable measure of PA among adolescents.

Implications for adolescent health

Assessing PA levels using the IPAQ-SF can have important implications for adolescent health. It can help schools to identify adolescents who are not meeting recommended levels of PA, to plan interventions, monitor progress, evaluate physical education programmes, and promote physical activity among adolescents:

- Adolescence is a critical period for establishing healthy behaviors, and regular PA is an important component of a healthy lifestyle. The IPAQ-SF can help identify students who are not meeting recommended levels of PA. Using the IPAQ-SF we can collect information that can be used to target interventions to increase PA levels among adolescents.
- The data collected from the IPAQ-SF can be used to plan interventions to increase PA levels among adolescents. For example, schools can use this information to develop PA programmes that are tailored to the needs of their students.
- Schools can use the IPAQ-SF to monitor the progress of their PA interventions. This can help them identify which interventions are most effective and make adjustments as needed.
- Schools can evaluate the effectiveness of their physical education programmes. This can help them identify areas where they can improve their programmes to better meet the needs of their students.
- The data collected from the IPAQ-SF can be used to promote PA among adolescents, creating awareness campaigns about the benefits of PA.

Limitations

The main limitation of our study is the modality of objective measurement, as it could not be used to assess the total PA of our participants. Another limitation is that we included only students who had iPhone, as it was the only possibility for the objective examination of physical activity. We opted for iPhone use, instead of other smartphone applications for steps measurement in order to provide the uniformity of measures. IPAQ-SF assesses only the PA that lasts longer than ten minutes, while the pedometers measure all steps, without restrictions on duration. Nonetheless, this is the first study to examine the validity and reliability of the Serbian version of IPAQ-SF in the population of adolescents and to examine its correlation with the objectively measured PA.

Our study showed that the IPAQ-SF has acceptable reliability in the population of adolescents and that it has a good validity. The PA measured by IPAQ-SF was slightly higher compared to the PA measured by pedometer, but pedometers do not assess number of different PA types. On the other hand, the overestimation of PA when using subjective measures was previously shown and although it requires caution in the interpretation of the results, has numerous advantages, especially in the population studies.

References

Apple. (2013). *Apple Announces iPhone 5s—The most forward-thinking smartphone in the world—Apple*. https://www.apple.com/newsroom/2013/09/10Apple-Announces-iPhone-5s-The-Most-Forward-Thinking-Smartphone-in-the-World/

Asigbee, F.M., Whitney, S.D., & Peterson, C.E. (2018). The link between nutrition and physical activity in increasing academic achievement. *Journal of School Health*, *88*(6), 407-415. https://doi.org/10.1111/josh.12625

Bankmycell. (2023). *How many people have smartphones worldwide*. https://www.bankmycell.com/blog/how-many-phones-are-in-the-world

Bhatt, G.C. (2016). Childhood obesity as a global concern. *Journal of Child Obesity*, *1*, 3-4. https://doi.org/10.21767/2572-5394.100

Caillaud, C., Ledger, S., Diaz, C., Clerc, G., Galy, O., & Yacef, K. (2022). iEngage: A digital health education program designed to enhance physical activity in young adolescents. *PLoS ONE*, *17*(10), e0274644. https://doi.org/10.1371/journal.pone.0274644

Case, M.A., Burwick, H.A., Volpp, K.G., & Patel, M.S. (2015). Accuracy of smartphone applications and wearable devices for tracking physical activity data. *JAMA—Journal of the American Medical Association*, *313*(6), 625-626. https://doi.org/10.1001/jama.2014.17841

Chaput, J., Willumsen, J., Bull, F., Chou, R., Ekelund, U., Firth, J., Jago, R., Ortega, F.B., & Katzmarzyk, P.T. (2020). 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5 – 17 years: Summary of the evidence. *International Journal of Behavioral Nutrition and Physical Activity*, *17*, 141-150. https://doi.org/10.1186/s12966-020-01037-z

Djurdjevic, D., Nikolic, A., Mazic, S., & Sipetic-Grujicic, S. (2023). Association between eating habits and low physical activity in adolescents. *Vojnosanitetski Pregled*, *81*(1), 45-51. https://doi.org/10.2298/VSP230131058D

Ehrler, F., Weber, C., & Lovis, C. (2016). Influence of pedometer position on pedometer accuracy at various walking speeds: A comparative study. *Journal of Medical Internet Research*, *18*(10), e268. https://doi.org/10.2196/JMIR.5916

Fillon, A., Pereira, B., Vanhelst, J., Baran, J., Masurier, J., Guirado, T., Boirie, Y., Duclos, M., Julian, V., & Thivel, D. (2022). Development of the Children and Adolescents Physical Activity and Sedentary Questionnaire (CAPAS-Q): Psychometric validity and clinical interpretation. *International Journal of Environmental Research and Public Health*, *19*(21), 13782. https://doi.org/10.3390/IJERPH192113782/S1

Harraqui, K., Oudghiri, D.E., Mrabti, H.N., Hannoun, Z., Lee, L.-H., Assaggaf, H., Qasem, A., Goh, K.W., Ming, L.C., Tan, C.S., Bouyahya, A., & Bour, A. (2023). Association between physical activity, body composition, and metabolic disorders in middle-aged women of Ksar el Kebir (Morocco). *International Journal of Environmental Research and Public Health*, *20*(3), 1739. https://doi.org/10.3390/ijerph20031739

Höchsmann, C., Knaier, R., Eymann, J., Hintermann, J., Infanger, D., & Schmidt-Trucksäss, A. (2018). Validity of activity trackers, smartphones, and phone applications to measure steps in various walking conditions. *Scandinavian Journal of Medicine and Science in Sports*, *28*(7), 1818-1827. https://doi.org/10.1111/sms.13074

Keating, X.D., Zhou, K., Liu, X., Hodges, M., Liu, J., Guan, J., Phelps, A., & Castro-Piñero, J. (2019). Reliability and concurrent validity of Global Physical Activity Questionnaire (GPAQ): A systematic review. *International Journal of Environmental Research and Public Health*, *16*(21), 4128. https://doi.org/10.3390/ijerph16214128

Koo, T.K., & Li, M.Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Lachat, C.K., Verstraeten, R., Khanh, L.N.B., Hagströmer, M., Khan, N.C., Van, N.D.A., Dung, N.Q., & Kolsteren, P.W. (2008). Validity of two physical activity questionnaires (IPAQ and PAQA) for Vietnamese adolescents in rural and urban areas. *International Journal of Behavioral Nutrition and Physical Activity*, *5*, 37. https://doi.org/10.1186/1479-5868-5-37

Lavie, C.J., Ozemek, C., Carbone, S., Katzmarzyk, P.T., & Blair, S.N. (2019). Sedentary behavior, exercise, and cardiovascular health. *Circulation Research*, *124*, 799-815. https://doi.org/10.1161/CIRCRESAHA.118.312669

Major, M.J., & Alford, M. (2016). Validity of the iPhone M7 motion co-processor as a pedometer for able-bodied ambulation. *Journal of Sports Sciences*, *34*(23), 2160-2164. https://doi.org/10.1080/02640414.2016.1189086

Monyeki, M., Moss, S., Kemper, H., & Twisk, J. (2018). Self-reported physical activity is not a valid method for measuring physical activity in 15-year-old South African boys and girls. *Children*, *5*(6), 71. https://doi.org/10.3390/children5060071

NHS—National Health Service. (2019). *Physical activity guidelines for children and young people*. Available at: https://www.nhs.uk/live-well/exercise/physical-activity-guidelines-children-and-young-people/

Nolan, M., Mitchell, J.R., & Doyle-Baker, P.K. (2014). Validity of the Apple iPhone®/iPod Touch® as an accelerometer-based physical activity monitor: A proof-of-concept study. *Journal of Physical Activity and Health*, *11*(4), 759-769. https://doi.org/10.1123/jpah.2011-0336

Rääsk, T., Maëstu, J., Lätt, E., Jürimäe, J., Jürimäe, T., Vainik, U., & Konstabel, K. (2017). Comparison of IPAQ-SF and two other physical activity questionnaires with accelerometer in adolescent boys. *PLoS ONE*, *12*(1), e0169527. https://doi.org/10.1371/journal.pone.0169527

Ramakrishnan, R., He, J.R., Ponsonby, A.L., Woodward, M., Rahimi, K., Blair, S.N., & Dwyer, T. (2021). Objectively measured physical activity and all cause mortality: A systematic review and meta-analysis. *Preventive Medicine*, *143*, 106356. https://doi.org/10.1016/j.ypmed.2020.106356

Rangul, V., Holmen, T.L., Kurtze, N., Cuypers, K., & Midthjell, K. (2008). Reliability and validity of two frequently used self-administered physical activity questionnaires in adolescents. *BMC Medical Research Methodology*, *8*, 47. https://doi.org/10.1186/1471-2288-8-47

Romeo, A., Edney, S., Plotnikoff, R., Curtis, R., Ryan, J., Sanders, I., Crozier, A., & Maher, C. (2019). Can smartphone apps increase physical activity? Systematic review and meta-analysis. *Journal of Medical Internet Research*, *21*(3), e12053. https://doi.org/10.2196/12053

Sember, V., Meh, K., Sorić, M., Jurak, G., Starc, G., & Rocha, P. (2020). Validity and reliability of International Physical Activity Questionnaires for Adults across EU countries: Systematic review and meta analysis. *International Journal of Environmental Research and Public Health*, *17*(19), 7161. https://doi.org/10.3390/IJERPH17197161

Sullivan, A.N., & Lachman, M.E. (2017). Behavior change with fitness technology in sedentary adults: A review of the evidence for increasing physical activity. *Frontiers in Public Health*, *4*(JAN), 289. https://doi.org/10.3389/FPUBH.2016.00289

Todorovic, J., Terzic-Supic, Z., Djikanovic, B., & Nesic, D. (2019). Can social media intervention improve physical activity of medical students ? *Public Health*, *174*, 69-73. https://doi.org/10.1016/j.puhe.2019.05.030

Wang, C., Chen, P., & Zhuang, J. (2013). Validity and reliability of International Physical Activity Questionnaire-Short Form in Chinese youth. *Research Quarterly for Exercise and Sport*, *84*(SUPPL. 2), 37-41. https://doi.org/10.1080/02701367.2013.850991

Wang, Z., Jiang, B., Wang, X., Li,Z., Wang, D., Xue, H., & Wang, D. (2023). Relationship between physical activity and individual mental health after traumatic events: a systematic review. *European Journal of psychotraumatology*, *14*(2), 2205667. https://doi.org/10.1080./20008066.2023.2205667

WHO—World Health Organization. (2020). *Physical activity*. Available at: https://www.who.int/news-room/fact-sheets/detail/physical-activity

WHO—World Health Organization. (2022). *Physical inactivity*. Available at: https://www.who.int/data/gho/indicator-metadata-registry/imr-details/3416

Submitted: April 9, 2024
Accepted: August 26, 2024
Published Online First: December 17, 2024

Correspondence to:
Dragan Djurdjevic
Department of Sports Medicine, Faculty of Medicine,
University of Belgrade, Serbia
Visegradska 26/2, 11000 Belgrade, Serbia
e-mail: d_djurdjevic@yahoo.com
phone: +381 64 1133 110

DO STRESS TESTS REFLECT THE INTENSITY REACHED DURING COMPETITION IN AMATEUR MEN'S BASKETBALL?

Abraham Batalla-Gavalda[1,2], Jose Vicente Beltran-Garrido[3], Gerson Garrosa-Martín[1], Raúl Montoliu-Colás[4], and Francisco Corbi[5]

[1]University School of Health and Sport (EUSES), Universitat Rovira i Virgili, Amposta, Spain
[2]INEFC Barcelona Sports Sciences Research Group, University of Barcelona, Barcelona, Spain
[3]Physical Exercise and Performance Research Group, Department of Education Science, School of Humanities and Communication Sciences, Universidad Cardenal Herrera-CEU, CEU Universities, Castellon de la Plana, Spain.
[4]Institute of New Imaging Technologies (INIT), Jaume I University, Castellón, Spain
[5]National Institute of Physical Education of Catalonia, Facultat de Lleida, University of Lleida, Lleida, Spain

Original scientific paper
DOI 10.26582/k.56.2.14

Abstract:

In recent years, stress tests have emerged as one of the best ways to assess fitness and health of athletes. However, there is some controversy as to their ability to replicate the actual physiological needs generated during competition. The aim of the study was to compare the levels of various physiological variables measured during laboratory stress tests with those observed during competition. Heart rate, blood lactate, blood pressure, rate of perceived effort and stress level were analysed in ten amateur male basketball players, during three maximal laboratory tests (TREADMILL, CYCLE and Wingate test), and in five official competition games. The level of significance for the study was set at $p \leq .05$. Statistically significant differences between the physiological needs of competitive matches and those of stress tests were reported ($p < .05$). Furthermore, the time during which a higher HR was recorded during the competition compared to the HR obtained during the stress tests was calculated. This time was 12.36 ± 9.21% of the Live Time (LT) on TREADMILL, 35.04 ± 11.78% of the LT on CYCLE and 63.75 ± 11.57% of the LT on Wingate. The results suggest that laboratory stress tests do not reproduce the physiological requirements imposed on amateur basketball players during competition.

Key words: *amateur basketball, stress testing, perceived effort, intensity, physiological needs*

Introduction

In recent years, an increase in the number of cardiovascular accidents occurring during sport competitions has been observed (Emery & Kovacs, 2018), which has been related to several factors such as the continuous increase in the number of sport practitioners, the type of sources consulted when accounting for accidents (media, insurance reports or sport federations) (Harmon, Zigman, & Drezner, 2015), the inclusion criteria used in epidemiological studies (Hajduczok, Ruge, & Emery, 2022) and, more recently, an increase in the number of myocarditis caused by coronavirus 2 (SARS-CoV-2) (Daniels, et al., 2021). Moreover, it seems the variation in incidence depends on several factors such as race, gender and the intensity at which the sport is done (Maron, Haas, Ahluwalia, Murphy, & Garberich, 2016). Although some authors suggest a higher incidence among high-level athletes, in some countries such as Spain, 96% of athletes who suffered a sudden death were recreational or amateur athletes (Morentin, et al., 2021), showing a direct relationship between a lower level of physical fitness and a higher probability of suffering a serious cardiovascular accident (Kokkinos, et al., 2017).

Therefore, early detection of cardiovascular pathology prior to any physical activity is particularly important (Çetin, Ekici, Kibar, Sürücü, & Orgun, 2018). A complete anamnesis, physical examination and 12-lead resting electrocardiogram are some of the recommended tools for early detection of cardiac impairment (Löllgen & Leyk, 2018). In addition, the heart rate achieved during high-intensity physical exercise has been associated with an increased risk of sudden death (predictive factor), especially when the exercise is strenuous (Jouven et al., 2005). On the other hand, several studies suggest that the combination of high training volumes and intensities could lead to negative cardiac adaptations such as accelerated coronary artery calcification, acute release of cardiac biomarkers or the development of certain pathologies such as myocardial fibrosis or atrial fibrillation (Franklin, et al., 2020). For example, in recent years, an increase in the latter pathology has been observed in high-intensity endurance sports (Estes & Madias, 2017).

In this regard, the American College of Sports Medicine (ACSM) suggested that the best way for early detection of cardiovascular pathology is the performance of a maximal stress test (American College of Sports Medicine, Liguori, Feito, Fountaine, & Roy, 2021). This has been defined as "a non-invasive procedure that provides diagnostic information on cardiopulmonary function and assesses individual dynamic exercise capacity" (Myers, et al., 2009).

Furthermore, apart from their usefulness for the assessment of physical performance capacity and advice before the start of training, they could also be used as a tool for: 1) the assessment of the general state of health of the athlete, 2) the detection of various cardiovascular and metabolic pathologies that could limit and/or contraindicate the practice of physical exercise and sport (Löllgen & Leyk, 2018), and 3) as a way of assessing the evolution of sporting performance throughout a competitive season.

Given that a direct relationship has been observed between the inability to reach certain heart rates—calculated from an estimated maximum heart rate—and an increased risk of death from cardiovascular disease (Harber, et al., 2017), for this type of assessment to be effective, the athlete must reach maximum intensities (HRmax) during performance (Hamlin, Draper, Blackwell, Shearman, & Kimber, 2012).

Therefore, a stress test should reproduce the maximum intensity levels at which the athlete performs when doing sport in order to be considered effective (Currell & Jeukendrup, 2008), since the intensity reached could determine whether a pathology can be detected or, on the contrary, would go undetected. As such, it is essential that the intensity of effort reached during the performance of an exercise test is equal to or higher than that the athlete will attain during the competition and that there are no significant differences between the two (Santos, et al., 2012). In fact, the performance of a stress test without meeting the completion criteria, which ensures maximum effort by the participant, is considered a cause of a false negative in the performance of the test (Higgins & Higgins, 2007). Moreover, the existing differences may vary depending on the sport, the type of ergometer (treadmill, cycle ergometer...), the population group practising, and, finally, they may also be influenced by various psychological factors such as stress or anxiety (Sánchez-Beleña & García-Naveira Vaamonde, 2017).

Unfortunately, as far as we are aware, there are no studies in basketball that have made an in-depth analysis of the differences between the intensity levels reached during stress tests and during competition, which opens the door to questioning whether the intensities reached during stress tests are high enough to reflect the true intensity developed during competition. On the other hand, in many cases the players and/or the clubs they play for do not have qualified personnel and/or laboratories where all these aspects can be assessed, so many assessments are carried out by applying field tests (Durmić, et al., 2019).

On the other hand, although during the performance of the laboratory tests an attempt is made to reproduce the conditions and patterns applied during competition (movement patterns, types of effort, duration, etc.), the need to apply standardised protocols, the performance of the tests in a limited space and the impossibility of adapting the type of test used to all movement patterns and sports, means that the tests are performed in reduced spaces and using instruments such as the cycle ergometer or treadmill, which could cause a change in the performance conditions that would limit the intensities achieved in the tests. This could lead to very different perceptions of fatigue depending on the assessment conditions used.

Therefore, the main objective of this study was to analyse whether there were differences between the values of various physiological and psychological variables related to cardiovascular pathology, obtained in different maximal stress tests performed in the laboratory and the values obtained during official competition, in a group of amateur male basketball players.

Methods

Experimental approach to the problem

The study was organised in two phases: Phase 1: pre-competitive period (two weeks before the start of the competition), in which the maximal laboratory tests were carried out, and Phase 2: competitive period, in which the physiological and psychological variables of the first five official matches (MATCH) were recorded.

The maximal laboratory tests consisted of the following: 1) a Wingate (WIN) test (Ayalon, Inbar, & Bar-Or, 1974), 2) a treadmill (TREADMILL) maximum incremental step-up test (Manoelles, 2005), and 3) a cycle ergometer (CYCLE) maximum incremental ramp test (Keir, et al., 2015). These tests were selected because they are the most commonly used in laboratory assessments during pre-season in many competitive sports (Manonelles, Franco, & Naranjo, 2016).

Two types of variables were monitored: 1) physiological: heart rate, blood lactate, and blood pressure, and 2) psychological: perceived level of effort and perceived stress. In the case of matches, HR data were recorded and the corresponding Live Time (LT; defined as "the time that elapses when the player is on the court, the ball is in play and the stopwatch is running") was considered for the analysis (McInnes, Carlson, Jones, & McKenna, 1995). The experimental design of the study is shown in Figure 1.

Participants

The study sample consisted of 10 amateur male basketball players (age: 21.40 ± 2.22 years; body height: 1.92 ± 0.07 m; body mass: 88.44 ± 8.52 kg; fat mass: 15.49 ± 3.41 %; years of practice: 12.40 ± 2.50 years), belonging to the top-level regional category (1st National Division). The players had three 2-hour training sessions per week and one match on the weekend. In addition, during the study, special care was taken to ensure that participants did not engage in moderate- or high-intensity physical activity apart from the assessment or regular training sessions. The participants had no personal or family history of cardiac pathology, nor had they suffered from any injury that could alter regular sports practice in the six months prior to the study.

To check the minimum effect size to which the statistical model was sensitive, a sensitivity analysis with the analysed sample size (n = 10, number of groups = 1, number of measurements = 4, and non-sphericity correction of $\varepsilon = 1$) was done. The power and alpha values used were 0.80 and 0.05, respectively. The model was sensitive enough to detect moderate effects of at least f = 0,39 or the equivalent d = 1,12 described as moderate (Hopkins, Marshall, Batterham, & Hanin, 2009).

None of the participants received any financial or in-kind reward for their collaboration in the study. They also signed an informed consent form, and a protocol was established for the delivery and explanation of the results. At the time of the study, none of the participants were taking any type of medication, nor were they following a specific dietary pattern, nor did they suffer from any respiratory or metabolic disorder.

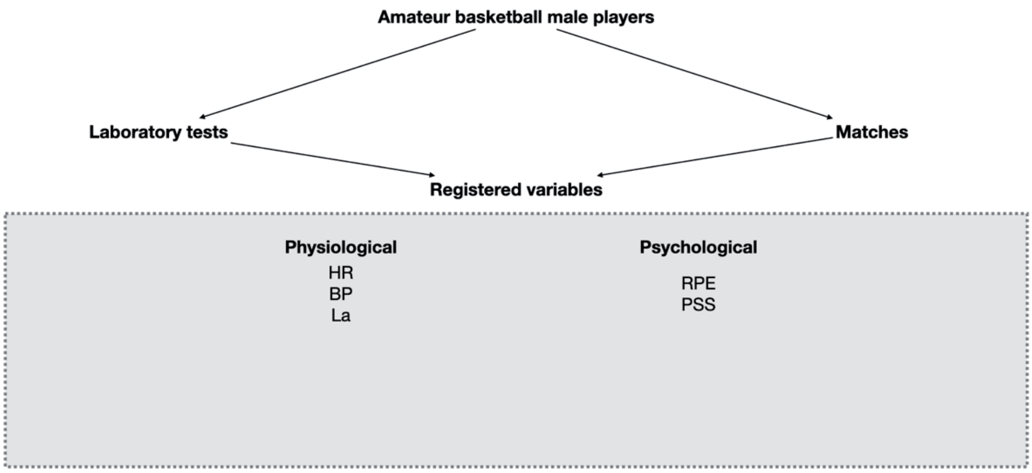
Procedures

The timing of the records of the variables is detailed in Table 1.

Information prior to the initiation of the research. Three days prior to the first exercise test, participants were contacted to remind them not to exercise or consume caffeinated or carbonated beverages at least 12 hours before the assessments. They were also not to smoke in the three hours prior to data collection.

Information protocol and consents in the laboratory. When they arrived at the laboratory, having understood the procedure to follow for data collection and clarified any queries they might have, they were asked to sign the informed consent form for the study and for the clinic where the stress tests were carried out.

Anamnesis and physical examination of the participants. A complete anamnesis and a 12-lead electrocardiogram were performed by a sports medicine physician in a specially equipped room (18-22°C and 40-60% relative humidity). In addition, anthropometry was assessed (height: Seca® 220 measuring rod with an accuracy of 0.1 cm; weight: Seca® 700 column scale, Germany with an accuracy of 0.05 kg; and body fat: BC-601 meter, Tanita® scale, with an accuracy of 0.1%).



Note. HR: heart rate; BP: blood pressure; La: lactate; RPE: rate of perceived exertion; PSS: perceived stress scale.

Figure 1. Experimental design.

Table 1. Timing of the recording of variables from laboratory tests and matches

Condition	Before	During	After
Laboratory tests			
Wingate	PSS BP La	HR	BP La RPE
Cycle ergometer	PSS BP La	HR	BP La RPE
Treadmill	PSS BP La	HR	BP La RPE
Matches	PSS BP La	HR	BP La RPE

Note. HR: heart rate; BP: blood pressure; La: lactate; RPE: rate of perceived exertion Borg-20; PSS: perceived stress scale.

Laboratory tests

Temporal organisation of stress tests. The laboratory assessments were divided into two recording sessions separated by 48 hours of recovery time. In the first session, the WIN test (Ayalon, et al., 1974) and the CYCLE test (Keir, et al., 2015) were performed, leaving a full recovery period of 30 min between the tests. In the second session, the TREADMILL test (Rabadán & Boraita, 2005) was performed. Half of the participants took the WIN and CYCLE on the first day, while the other half started with the TREADMILL and took the rest of the tests on the second day, in order to avoid that the order of the tests could influence the final result of the study.

Wingate test (WIN). It followed the protocol proposed by Ayalon et al. (1974). After a 5-minute warm-up on the cycle ergometer, the participant pedalled at the maximum possible speed for 30 seconds, and revolutions per minute (rpm) were collected every five seconds. The load applied was 75 g/kg body weight.

Cycle ergometer test (CYCLE). It followed the protocol described by Keir et al. (2015), which consists of a maximum incremental ramp test, starting at 20W for four minutes, increasing by 25W every minute, maintaining a pedalling cadence of between 70 and 100 rpm at all times.

TREADMILL test. A continuous stepwise maximum incremental test with a constant slope of 1% was performed. The test began with a 2-minute warm-up at 6 km/h with progressive increases of 1 km/h every minute (Manoelles, 2005).

Competitive matches

The week before the start of the recording of physiological and psychological variables during the competition, a friendly match was organised so that both the participants and the research team could familiarise themselves with the data collection protocol. Subsequently, the first five official competition matches were assessed.

Recording of physiological variables

Heart rate. Polar Team heart rate monitors (Polar Electro, Corp., Finland) with a recording rate of 1 Hz (second by second) were used for HR monitoring. At the same time, the matches were recorded with two video cameras (JVC -GZ620SE HDD. Hong Kong, China) synchronised with the heart rate monitors by means of an acoustic and visual signal, just before the start of the warm-up. The cameras were placed in an elevated position in the grandstand from where they could record at least half of the arena without having to be moved. The heart rate monitors were placed 10 minutes before the start of the warm-up (36 min before the start of the matches, the specific warm-up had a duration of 26 min). The recording was synchronised acoustically and visually with the video cameras at the beginning and end of each quarter.

Blood pressure. An OMRON HEALTHCARE M2 Basic (HEM-7120-E) sphygmomanometer (Derivative of Omron HEM-7130) was used for blood pressure assessment following the recommendations proposed by James and Gerber (2018). This model was previously validated by Takahashi, Yoshika, and Yokoi, (2015). The assessments were carried out before and after each test and each match.

Lactate. Blood samples were drawn from the earlobe of each participant following the protocol proposed by Sanchez-Arjona, Ruiz Martínez, and Martín Fernández (2008). For this purpose, the lactate scout photometer (Lactate Plus DP110, Diaglobal GmbH, Berlin, Germany) was used. Measurements were taken before and after each test and match, following the protocol by Warr-di Piero, Valverde-Esteve, Redondo-Castán, Pablos-Abella, and Sánchez-Alarcos Díaz-Pintado (2018).

Recording of psychological variables

Perceived Stress Scale (PSS). The Spanish version of the Perceived Stress Scale (PSS) (Remor, 2006) was administered before each test and match. This questionnaire is a self-report instrument that assesses the level of perceived stress over the past month, consisting of 14 items with a five-point scale response format (0 = never, 1 = hardly ever, 2 = occasionally, 3 = often, 4 = very often). The total PSS score is obtained by inverting the scores of items 4, 5, 6, 7, 9, 10 and 13 (in the following sense: 0 = 4, 1 = 3, 2 = 2, 3 = 1 and 4 = 0) and then adding up the 14 items. The direct score obtained indicates that a higher score corresponds to a higher level of perceived stress.

Rate of Perceived Exertion (RPE). The original Borg Scale (Borg, 1982), consisting of 15 items (6-20), where 6 is a very, very mild perception, and 20 is a very, very hard perception, was administered in response to the question "How hard have I tried relative to my 100% effort?". The scale was administered after each test and match (30 min after) and during match breaks.

Statistical analyses

To compare the psycho-physiological demands of Match, Wingate, Treadmill and Cycle Ergometer conditions, a repeated measure analysis of variance (ANOVA) was used. Normality assumptions were checked using the Shapiro-Wilk test and exploring the Q-Q plots and the histogram plot of the residuals. Assumptions of sphericity were evaluated using the Mauchly's test. When sphericity was violated (p≤.05), the Greenhouse-Geisser correction factor was applied. Whenever a significant main effect was observed, *post-hoc* comparisons were performed with the Bonferroni correction. Effect sizes were evaluated using a partial omega squared (ω^2), with 0.06, 0.06-0.14, and > 0.14 indicating a small, medium, and large effect, respectively. Mean difference was obtained and the standardised mean difference Cohen's *d* effect size was calculated (Lakens, 2013), where *t* is the *t* statistic and *n* is the sample size. Effect sizes were interpreted as: < 0.2 = trivial; 0.2-0.6 = small; 0.6-1.2 = moderate; 1.2-2.0 = large; > 2.0 = very large (Hopkins, et al., 2009). The level of significance was set at 0.05 for all the tests. Statistical analyses were performed using JASP for Mac (version 0.16.4; JASP Team, 2024).

Results

The descriptive values of the different dependent variables measured are shown in Tables 2, 3, and 4. The percentage of time of the LT in which the player's heart rate stayed above the registered heart rate max of each laboratory test is shown in Figure 2.

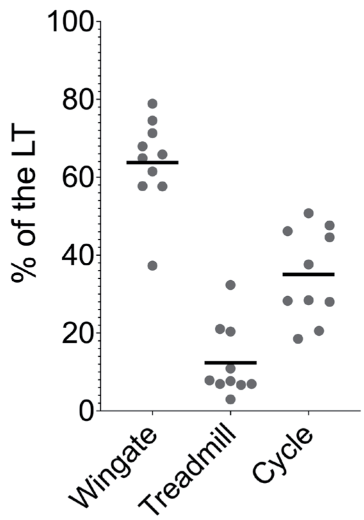


Figure 2. Percentage of time of the live time (LT) in which the player's heart rate stays above the registered heart rate max of each laboratory test.

Table 2. Values of the HR variables measured in the different conditions

Variable	Match	Wingate	Treadmill	Cycle ergometer
HRmax	197.91 ± 4.72	164.90 ± 12.19 *VL	188.70 ± 8.49 *M	179.60 ± 8.87 *VL
z0	0.00 ± 0.00	0.00 ± 0.00	8.88 ± 6.49 *VL	0.14 ± 0.46
z1	0.00 ± 0.00	1.00 ± 3.16	9.17 ± 4.15 *VL	4.97 ± 9.36 *M
z2	1.09 ± 0.73	6.00 ± 7.17	12.71 ± 5.21 *VL	16.43 ± 14.32 *VL
z3	9.91 ± 4.88	22.67 ± 4.10 *VL	13.77 ± 3.07	21.01 ± 8.78 *VL
z4	43.84 ± 9.91	25.00 ± 4.23 *VL	20.97 ± 6.26 *VL	24.04 ± 7.71 *VL
z5	45.16 ± 13.55	45.33 ± 9.96	34.50 ± 5.78 *M	33.40 ± 7.17 *VL

Note. Values are presented as mean ± SD. Match_LT: mean values of the heart rate variables for the match condition during the live time; Wingate: mean values of the heart rate variables for the Wingate condition; Treadmill: mean values of the heart rate variables for the treadmill condition; Cycle ergometer: mean values of the heart rate variables for the cycle ergometer condition; z0: percentage of minutes accumulated under 50% of the heart rate maximum; z1: percentage of minutes accumulated between 50 and 60 % of the heart rate maximum; z2: percentage of minutes accumulated between 60 and 70 % of the heart rate maximum; z3: percentage of minutes accumulated between 70 and 80 % of the heart rate maximum; z4: percentage of minutes accumulated between 80 and 90 % of the heart rate maximum; z5: percentage of minutes accumulated between 90 and 100 % of the heart rate maximum; *p≤.05 statistically significantly different from match values; T: trivial effect size; S: small effect size; M: medium/moderate effect size; L: large effect size; VL: very large effect size.

Table 3. Values of the psychological variables measured in the different conditions

Variable	Match	Wingate	Treadmill	Cycle ergometer
RPE-20	14.13 ± 2.31	16.20 ± 0.92 *L	18.20 ± 0.42 *VL	18.30 ± 0.95 *VL
Stress	10.17 ± 4.26	10.40 ± 3.41	7.60 ± 5.52	10.40 ± 3.41

Note. Values are presented as mean ± SD. Match: mean values of the psychological variables for the match condition; Wingate: mean values of the psychological variables for the Wingate condition; Treadmill: mean values of the psychological variables for the treadmill condition; Cycle ergometer: mean values of the psychological variables for the cycle ergometer condition; RPE-20: Rate of perceived exertion; Stress: Perceived stress scale; *p≤.05 statistically significantly different from match values; T: trivial effect size; S: small effect size; M: medium/moderate effect size; L: large effect size; VL: very large effect size.

Table 4. Values of the lactate and blood pressure variables measured in the different conditions

Variable	Match	Wingate	Treadmill	Cycle ergometer
Lactate	(mmol/L)			
Pre	0.85 ± 0.07	0.94 ± 0.05	0.94 ± 0.13	0.95 ± 0.05
Post	4.12 ± 1.20	12.02 ± 0.87 *VL	6.99 ± 0.54 *VL	6.59 ± 0.35 *VL
Blood pressure	(mm Hg)			
SBP_pre	130.17 ± 5.39	125.50 ± 7.62	125.00 ± 12.02	125.00 ± 9.13
SBP_post	125.33 ± 6.15	165.50 ± 13.43 *VL	166.00 ± 8.43 *VL	177.00 ± 13.37 *VL
DBP_pre	74.73 ± 4.30	71.00 ± 7.38	65.50 ± 4.97*L	72.00 ± 7.89
DBP_post	77.45 ± 3.65	70.00 ± 6.67 *L	62.50 ± 3.54 *VL	66.50 ± 3.37 *VL

Note. Values are presented as mean ± SD. Match: mean values of the lactate and blood pressure variables for the match condition; Wingate: mean values of the lactate and blood pressure variables for the Wingate condition; Treadmill: mean values of the lactate and blood pressure variables for the treadmill condition; Cycle ergometer: mean values of the lactate and blood pressure variables for the cycle ergometer condition; SBP: systolic blood pressure; DBP: diastolic blood pressure; *p≤.05 statistically significantly different from match values; T: trivial effect size; S: small effect size; M: medium/moderate effect size; L: large effect size; VL: very large effect size.

Match vs. Wingate differences

Regarding the HR variables, statistically significant lower values of HRmax (very large) and z4 (very large) variables were shown in Wingate than in Match. However, statistically significant higher values of z3 (very large) were shown in Wingate than in Match (Table 2).

Regarding the psychological variables, significant higher values of RPE-20 (very large) were shown in Wingate than in Match (Table 3).

Regarding the lactate and blood pressure variables, statistically significant lower values of DBP_post (large) were shown in Wingate than in Match. However, statistically significant higher values of Lactate at post condition (very large) and SBP_post (very large) were shown in Wingate than in Match (Table 4).

Finally, when the Wingate test was performed, 63.75 % of the time of the LT the players' heart rate stayed above the registered HRmax in the test itself (Figure 2).

Match vs. cycle ergometer differences

Regarding the HR variables, statistically significant lower values of HRmax (very large), z4 (very large) and z5 (very large) variables were shown in Cycle ergometer than in Match. However, statistically significant higher values of z1 (moderate), z2 (very large) and z3 (very large) variables were shown in Cycle ergometer than in Match (Table 2).

Regarding the psychological variables, statistically significant higher values of RPE-20 (very large) were shown in Cycle ergometer than in Match (Table 3).

Regarding the lactate and blood pressure variables, statistically significant lower values of DBP_post (very large) variables were shown in Cycle ergometer than in Match. However, statistically significant higher values of lactate at post condition (very large) and SBP_post (very large) were shown in Treadmill than in Match (Table 4).

Finally, when the Cycle ergometer test was performed, 35.04 % of the time of the LT the players' heart rate stayed above the registered HRmax in the test itself (Figure 2).

Match vs. treadmill differences

Regarding the HR variables, statistically significant lower values of HRmax (moderate) and z5 (moderate) variables were shown in Treadmill than in Match. However, statistically significant higher values of z0 (very large), z1 (very large), z2 (very large) and z5 (moderate) variables were shown in Treadmill than in Match (Table 2).

Regarding the psychological variables, statistically significant higher values of RPE-20 (very large) were shown in Treadmill than in Match (Table 3).

Regarding the lactate and blood pressure variables, statistically significant lower values of DBP_ pre (large) and DBP_post (very large) variables were shown in Treadmill than in Match. However, statistically significant higher values of Lactate at post condition (very large) and SBP_post (very large) were shown in Treadmill than in Match (Table 4).

Finally, when the Treadmill test was performed, 12.36 % of the time of the LT the players' heart rate stayed above the registered HRmax in the test itself (Figure 2).

Discussion and conclusions

This is the first study, at least to our knowledge, to compare the differences between the intensity achieved during various laboratory stress tests and the intensity recorded during an official competition in amateur men's basketball. The results seem to confirm the existence of differences between the two conditions in some of the variables analysed. Although the intensity levels observed were higher during the competition, the levels of RPE, lactate and blood pressure were found to be lower than in the stress tests. In contrast, no significant differences were observed in the vast majority of variables between conditions prior to the match, ensuring that the tests and the match were conducted under equal conditions.

Match vs. Wingate differences

Basketball is a sport with a combination of high intensity aerobic and anaerobic actions (Petway, Freitas, Calleja-González, Medina Leal, & Alcaraz, 2020) and lactate concentrations ranging from 2.7 to 6.8mmol-L-1 (Stojanović, et al., 2018), suggesting the importance of the glycolytic pathway in energy production. The Wingate test is a maximal anaerobic test in which the adenosine triphosphate-phosphocreatine system and the glycolytic system are significantly stimulated, activating purine catabolism and lactate production (Granier, Mercier, Mercier, Anselme, & Préfaut, 1995; Sawada, et al., 2023). This makes it the gold standard tool for monitoring improvements in anaerobic capacity and power in sports where anaerobic metabolism is clearly involved (Bar-Or, 1987; Dobashi, Katagiri, Fujii, & Nishiyasu, 2023). It is also the most commonly used test to assess anaerobic performance in some groups such as athletes with disabilities (Marszałek, et al., 2019).

This test has been used in basketball as a way of assessing anaerobic performance, both in competitive players and young basketball players (Apostolidis, Nassis, Bolatoglou, & Geladas, 2004; Gholami, Ali, Hasani, & Zarei, 2022), although its usefulness has been questioned, due to the fact that its duration allows the assessment of capacity and not so much anaerobic power, which seems to be the most relevant in basketball (Delextrat & Cohen, 2008).

Despite this, it has been used in the field of prevention and health promotion as a way of assessing cardiac and respiratory function and arterial response to exercise (Coates, Millar, & Burr, 2023; Iamonti, et al., 2022). In our study, this test was used because of its simplicity and short duration and because it can be applied in conjunction with other laboratory tests in the same assessment session, which means that it is used by many clubs as a complementary test to the stress test. Furthermore, it seems that this test could correlate with other anaerobic track tests (Fatouros, et al., 2011; Yanci, et al., 2014), which would allow us to obtain a first approximation of the state of this pathway in the athletes analysed.

When comparing the results obtained between the WIN test and the MATCH, we observed that the HR levels achieved were lower in the WIN than in the MATCH, with the exception of the z3 values. This could indicate that the players did not reach the maximum heart rate intensity during the test (see Table 2). This may be due to the short duration of the WIN test (30 seconds). However, the subjective perception of reported effort was higher in the WIN test (see Table 3). This could indicate that, although the intensity during the test was not maximal, the perception of exertion experienced by the participant during the test was maximal. This point leads to the view that individual perception of effort should not be considered as synonymous with the level of intensity achieved, which could lead to a false-negative, when the aim is to ensure the cardiovascular health of the athlete (Higgins & Higgins, 2007).

Although this could be attributed to the fact that the lactate values achieved in the WIN test were significantly higher (large effect size), since for many years there has been a certain consensus on the idea that the higher the lactate concentration, the greater the subjective perception of effort, recent studies question this relationship (Lee, et al., 2023). In addition, it seems that intermittent exercises, such as basketball practice, could generate a "rebound effect" that would generate a lower perception of effort, generating more pleasurable effects (Jung, Bourne, & Little, 2014), which would suggest that the subjective perception of effort should be greater in continuous efforts. On the other hand, the data collection of all players was performed following the protocol proposed during the stress tests by Warr-di Piero et al. (2018), consisting of the collection of lactate and blood pressure values after the end of the effort. However, the application of this protocol during competition can only be effectively carried out on players who have finished the match on court, losing the information on lactate kinetics during competition. In addition, several studies suggest that the specificity of the movement pattern to be assessed could influence the final result of the test, as it has been found that the higher the specificity and complexity of the test, the lower the performance during the test (Batra, 2019). This could be caused by the fact that stress tests are performed in a controlled and standardised environment (Weichenberger, Esefeld, & Müller, 2023), where all the player's attention is focused on completing the test with the best possible effort, whereas during competition, there are many variables that can affect the perceived effort, such as emotions, game strategy, the match environment or the score (Batalla Gavaldà, Bofill Ródenas, Montoliu Colás, & Corbi Soler, 2018; Sansone, Gasperi, Tessitore, & Gomez, 2021). In addition, the complexity and intermittent nature of movement patterns are also factors that should be considered, as in the case of the court movement patterns may vary depending on the needs of the game (Boutios, et al., 2022).

Blood pressure has been associated with an increased risk of cardiovascular disease (Yang, et al., 2021), although its influence will vary depending on various factors such as age, arterial elasticity and the existence of atheromatous plaques (Wu, et al., 2023). In our study, an increase in both post-exercise SBP and post-exercise BOD was observed in both tests, although this increase was greater in the WIN test. This fact could be explained by the different nature of the efforts made (continuous vs. intermittent high intensity) and by the existence of pauses during the competition, which would naturally tend to normalise blood pressure (Huang, et al., 2023). In addition, the high intensities reached, together with the fact that in the WIN test, the action of the arms and trunk are performed in a quasi-isometric manner, could further increase blood pressure in the trunk (Lässing, et al., 2023).

Match vs. cycle ergometer differences

When comparing the variables recorded between the MATCH and the CYCLE, significant differences of large or very large magnitude were observed in almost all the variables analysed (with the exception of the values recorded in z0, which did not present significant differences, and the values of z1, which presented significant differences of moderate magnitude), with the results obtained on the court being higher in relation to HRmax, % time spent in z4 and z5 (see Table 2), and DBP_post (see Table 4), and lower in % time spent in z1, z2 and z3 (see Table 2), and RPE-20 (see Table 3), lactate post, and SBP_post.

These differences could be due to a number of reasons. First, it is different types of efforts made in both situations. While in the CYCLE test a continuous effort is made (Keir, et al., 2015), in match situations the type of effort made involves actions of an intermittent high intensity (Khoramipour et al., 2021). In fact, as indicated by Hauer, Tessitore, Binder, and Tschan (2018), one of the elements to take into account is exercise density, i.e., the ratio of activity time to pause time within an event, as this can modify intensity levels. In addition, the alternation between high intensity and recovery in match situations could lead to spontaneous regulation of blood pressure behaviour, moderating the difference between the two variables (Ghasem, Abouzeid, Toresdahl, & Shah, 2022). Second, due to the fact that during the match the HR is in the z4 and z5 for more than 85% of the time, the workload at high intensity is considerably higher than in the CYCLE test. These values are similar to those reported by Sanders, Boos, Rhodes, Kollock, and Peacock (2021) in an NCAA female population, who found that players were at values above 85% of HRmax for an average of 34.5 minutes of the match. Third, the type of motor patterns performed during competition is very different from that used during the CYCLE test, since in pedalling actions, hip flexors and extensors would not be fully activated, contrary to what happens in running actions (Dorel, Guilhem, Couturier, & Hug, 2012). This justifies the greater capacity to generate power during competition, an aspect that allows higher levels of intensity to be reached (Medbø & Toska, 2001). Fourth, the change in blood pressure, which was much greater during the CYCLE test compared to the MATCH, as a result of peripheral vasoconstriction in the upper limbs and vasodilation in the lower limbs (Joyner & Casey, 2015).

Match vs. treadmill differences

A comparison of the variables analysed between the MATCH and the TREADMILL shows significant differences in the vast majority of the variables analysed. While HRmax and % at z4 and Z5 were higher during the competition, RPE-20, lactate and blood pressure were higher during the TREADMILL test. This aspect could be related, as mentioned above, to the conditions in which the test was carried out and the psychological factors that derive from its performance, as it is difficult to reproduce the emotional situations generated by the competition in a laboratory test (Khoramipour, et al., 2021).

In relation to the lactate levels obtained during the MATCH, these were similar to those obtained in previous studies carried out with players during competition (Ben Abdelkrim, El Fazaa, El Ati, & Tabka, 2007; McInnes, et al., 1995; Stojanović, et al., 2018). In addition, the ability to clear lactate also appears to be related to the position and type of movements performed by participants after exercise (Wilson, 2016) and there appears to be a movement pattern specificity in the recording of lactate concentrations (Legaz-Arrese, Munguía-Izquierdo, Carranza-García, & Torres-Dávila, 2011), which may be related to the amount of muscle mass recruited. On the other hand, the need to counteract the inertial loads generated by body mass on the vertical component during running may also lead to increased lactate concentrations (Quittmann et al., 2021).

Therefore, and as a result of the above, our study suggests that laboratory stress tests do not reproduce the real physiological needs that amateur basketball players have on the court during an official competition. All this suggests the need to adapt the assessment protocols to the real competitive context of amateur basketball, as it seems that the type of pattern selected for the assessments could contribute significantly to the final result of the test.

Limitations of the study

This study has several limitations. Firstly, the gas exchange during the stress tests was not assessed. Although from the respiratory exchange ratio we can know the level of involvement of the athlete during the test (Myers, et al., 2009) and whether this is a reflection of the true level of effort applied (Mehra, et al., 2006), there are significant drawbacks to these assessments, such as the necessity of specialized technology and knowledge how to use it, associated legal constraints, and practical issues like athlete's discomfort when using masks (Pinkstaff, Peberdy, Kontos, Finucane, & Arena, 2010). Additionally, the equipment requires regular calibration, and its use during competition is not feasible.

Secondly, due to the nature of official competition, certain variables (e.g., lactate levels and blood pressure) had to be measured post-competition. Regulations and methodological limitations prevented in-progress assessments, potentially leading to an underestimation of these as delays could allow partial recovery of the athletes (Ben Abdelkrim, et al., 2007).

Moreover, the study included only amateur basketball players, which limits the generalizability of the findings. The responses of professional athletes, with their advanced physiological and psychological characteristics, may differ significantly. This limitation is further emphasized by a relatively small sample size. Although the sensitivity analysis indicates that the study could identify moderate effects, the small sample size necessitates caution when drawing specific conclusions and making recommendations for new test protocols.

In summary, the findings highlight significant differences in the physiological and psychological variables analysed, suggesting that current laboratory stress test protocols do not accurately replicate the demands of competitive amateur men's basketball. Practical applications include the need to develop new laboratory and on-court test protocols that better mimic competitive conditions. This work justifies the introduction of modified and novel test approaches to more accurately reflect the reality of competition.

References

American College of Sports Medicine, Liguori, G., Feito, Y., Fountaine, C., & Roy, B. (Eds.). (2021). *ACSM's guidelines for exercise testing and prescription* (11th ed.). Philadelphia: Wolters Kluwer.

Apostolidis, N., Nassis, G.P., Bolatoglou, T., & Geladas, N.D. (2004). Physiological and technical characteristics of elite young basketball players. *The Journal of Sports Medicine and Physical Fitness*, *44*(2), 157-163.

Ayalon, A., Inbar, O., & Bar-Or, O. (1974). Relationships among measurements of explosive strength and anaerobic power. In R.C. Nelson & C.A. Morehouse (Eds.), *Biomechanics IV* (pp. 572-577). London: Macmillan Education UK. https://doi.org/10.1007/978-1-349-02612-8_85

Bar-Or, O. (1987). The Wingate Anaerobic Test: An update on methodology, reliability and validity. *Sports Medicine*, *4*(6), 381-394. https://doi.org/10.2165/00007256-198704060-00001

Batalla Gavaldà, A., Bofill Ródenas, A.M., Montoliu Colás, R., & Corbi Soler, F. (2018). Relación entre la frecuencia cardíaca y el marcador durante una fase de descenso. [Relationship between heart rate and the scoreboard during a relegation playoff]. *Apunts Educación Física y Deportes*, (136), 110-122. https://doi.org/10.5672/apunts.2014-0983.es.(2018/2).132.08

Batra, A. (2019). Monitoring anaerobic performance in combat sport athletes—Call for test specificity. *Sport Performance and Science Reports*, *53*, 1-3.

Ben Abdelkrim, N., El Fazaa, S., El Ati, J., & Tabka, Z. (2007). Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. Commentary. *British Journal of Sports Medicine*, *41*(2), 69-75. https://doi.org/10.1136/bjsm.2006.032318

Borg, G.A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377-381.

Boutios, S., di Cagno, A., Buonsenso, A., Centorbi, M., Iuliano, E., Calcagno, G., & Fiorilli, G. (2022). Does the type of anaerobic test matter? A comparison between the anaerobic intermittent kick test and Wingate anaerobic test in taekwondo athletes. *Sports*, *10*(10), 154. https://doi.org/10.3390/sports10100154

Çetin, İ.İ., Ekici, F., Kibar, A.E., Sürücü, M., & Orgun, A. (2018). The pre-participation screening in young athletes: Which protocol do we need exactly? *Cardiology in the Young*, *28*(4), 536-541. https://doi.org/10.1017/S1047951117002438

Coates, A.M., Millar, P.J., & Burr, J.F. (2023). Investigating the roles of exercise intensity and biological sex on postexercise alterations in cardiac function. *Journal of Applied Physiology*, *134*(2), 455-466. https://doi.org/10.1152/japplphysiol.00570.2022

Currell, K., & Jeukendrup, A.E. (2008). Validity, reliability and sensitivity of measures of sporting performance. *Sports Medicine*, *38*(4), 297-316. https://doi.org/10.2165/00007256-200838040-00003

Daniels, C.J., Rajpal, S., Greenshields, J.T., Rosenthal, G.L., Chung, E.H., Terrin, M., …, & Eimer, M. (2021). Prevalence of clinical and subclinical myocarditis in competitive athletes with recent SARS-CoV-2 infection: Results from the big ten COVID-19 cardiac registry. *JAMA Cardiology*, *6*(9), 1078. https://doi.org/10.1001/jamacardio.2021.2065

Delextrat, A., & Cohen, D. (2008). Physiological testing of basketball players: Toward a standard evaluation of anaerobic fitness. *Journal of Strength and Conditioning Research*, *22*(4), 1066-1072. https://doi.org/10.1519/JSC.0b013e3181739d9b

Dobashi, K., Katagiri, A., Fujii, N., & Nishiyasu, T. (2023). Combined effects of hypocapnic hyperventilation and hypoxia on exercise performance and metabolic responses during the Wingate anaerobic test. *International Journal of Sports Physiology and Performance*, *18*(1), 69-76. https://doi.org/10.1123/ijspp.2022-0121

Dorel, S., Guilhem, G., Couturier, A., & Hug, F. (2012). Adjustment of muscle coordination during an all-out sprint cycling task. *Medicine and Science in Sports and Exercise*, *44*(11), 2154-2164. https://doi.org/10.1249/MSS.0b013e3182625423

Durmić, T., Đjelić, M., Gavrilović, T., Antić, M., Jeremić, R., Vujović, A., …, & Zdravković, M. (2019). Usefulness of heart rate recovery parameters to monitor cardiovascular adaptation in elite athletes: The impact of the type of sport. *Physiology International*, *106*(1), 81-94. https://doi.org/10.1556/2060.106.2019.03

Emery, M.S., & Kovacs, R.J. (2018). Sudden cardiac death in athletes. *JACC: Heart Failure*, *6*(1), 30-40. https://doi.org/10.1016/j.jchf.2017.07.014

Estes, N.A.M., & Madias, C. (2017). Atrial fibrillation in athletes. *JACC: Clinical Electrophysiology*, *3*(9), 921-928. https://doi.org/10.1016/j.jacep.2017.03.019

Fatouros, I.G., Laparidis, K., Kambas, A., Chatzinikolaou, A., Techlikidou, E., Katrabasas, I., …, & Taxildaris, K. (2011). Validity and reliability of the single-trial line drill test of anaerobic power in basketball players. *The Journal of Sports Medicine and Physical Fitness*, *51*(1), 33-41.

Franklin, B.A., Thompson, P.D., Al-Zaiti, S.S., Albert, C.M., Hivert, M.-F., Levine, B.D., …, & On behalf of the American Heart Association Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health; Council on Cardiovascular and Stroke Nursing; Council on Clinical Cardiology; and Stroke Council. (2020). Exercise-related acute cardiovascular events and potential deleterious adaptations following long-term exercise training: Placing the risks into perspective–An update: A scientific statement from the American Heart Association. *Circulation*, *141*(13), 749. https://doi.org/10.1161/CIR.0000000000000749

Ghasem, W., Abouzeid, C., Toresdahl, B.G., & Shah, A.B. (2022). Updated blood pressure guidelines: Implications for athletes. *Current Hypertension Reports*, *24*(10), 477-484. https://doi.org/10.1007/s11906-022-01210-8

Gholami, F., Ali, A., Hasani, A., & Zarei, A. (2022). Effect of beta-alanine supplementation on exercise-induced cell damage and lactate accumulation in female basketball players: A randomized, double-blind study. *Journal of Human Kinetics*, *83*, 99-107. https://doi.org/10.2478/hukin-2022-0034

Granier, P., Mercier, B., Mercier, J., Anselme, F., & Préfaut, C. (1995). Aerobic and anaerobic contribution to Wingate test performance in sprint and middle-distance runners. *European Journal of Applied Physiology and Occupational Physiology*, *70*(1), 58-65. https://doi.org/10.1007/BF00601809

Hajduczok, A.G., Ruge, M., & Emery, M.S. (2022). Risk factors for sudden death in athletes, is there a role for screening? *Current Cardiovascular Risk Reports*, *16*, 97-109. https://doi.org/10.1007/s12170-022-00697-9

Hamlin, M., Draper, N., Blackwell, G., Shearman, J., & Kimber, N. (2012). Determination of maximal oxygen uptake using the Bruce or a novel athlete-led protocol in a mixed population. *Journal of Human Kinetics*, *31*(2012), 97-104. https://doi.org/10.2478/v10078-012-0010-z

Harber, M.P., Kaminsky, L.A., Arena, R., Blair, S.N., Franklin, B.A., Myers, J., & Ross, R. (2017). Impact of cardiorespiratory fitness on all-cause and disease-specific mortality: Advances since 2009. *Progress in Cardiovascular Diseases*, *60*(1), 11-20. https://doi.org/10.1016/j.pcad.2017.03.001

Harmon, K.G., Zigman, M., & Drezner, J.A. (2015). The effectiveness of screening history, physical exam, and ECG to detect potentially lethal cardiac disorders in athletes: A systematic review/meta-analysis. *Journal of Electrocardiology*, *48*(3), 329-338. https://doi.org/10.1016/j.jelectrocard.2015.02.001

Hauer, R., Tessitore, A., Binder, N., & Tschan, H. (2018). Physiological, perceptual, and technical responses to continuous and intermittent small-sided games in lacrosse players. *PLoS ONE*, *13*(10), e0203832. https://doi.org/10.1371/journal.pone.0203832

Higgins, J.P., & Higgins, J.A. (2007). Electrocardiographic exercise stress testing: An update beyond the ST segment. *International Journal of Cardiology*, *116*(3), 285-299. https://doi.org/10.1016/j.ijcard.2006.04.047

Hopkins, W.G., Marshall, S.W., Batterham, A.M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3-12. https://doi.org/10.1249/MSS.0b013e31818cb278

Huang, Z., Wang, B., Song, K., Wu, S., Kong, H., Guo, L., & Liang, Q. (2023). Metabolic and cardiovascular responses to continuous and intermittent plank exercises. *BMC Sports Science, Medicine and Rehabilitation*, *15*(1), 1. https://doi.org/10.1186/s13102-022-00613-z

Iamonti, V.C., Souza, G.F., Castro, A.A.M., Porto, E.F., Cruz, L.G.B., Colucci, E., …, & Jardim, J.R. (2022). Upper limb anaerobic metabolism capacity is reduced in mild and moderate COPD patients. *COPD: Journal of Chronic Obstructive Pulmonary Disease*, *19*(1), 265-273. https://doi.org/10.1080/15412555.2022.2079485

James, G.D., & Gerber, L.M. (2018). Measuring arterial blood pressure in humans: Auscultatory and automatic measurement techniques for human biological field studies. *American Journal of Human Biology*, *30*(1), e23063. https://doi.org/10.1002/ajhb.23063

JASP Team. (2024). *JASP* [Mac]. Retrieved from https://jasp-stats.org/

Jouven, X., Empana, J.-P., Schwartz, P.J., Desnos, M., Courbon, D., & Ducimetière, P. (2005). Heart-rate profile during exercise as a predictor of sudden death. *New England Journal of Medicine*, *352*(19), 1951-1958. https://doi.org/10.1056/NEJMoa043012

Joyner, M.J., & Casey, D.P. (2015). Regulation of increased blood flow (hyperemia) to muscles during exercise: A hierarchy of competing physiological needs. *Physiological Reviews*, *95*(2), 549-601. https://doi.org/10.1152/physrev.00035.2013

Jung, M.E., Bourne, J.E., & Little, J.P. (2014). Where does HIT fit? An examination of the affective response to high-intensity intervals in comparison to continuous moderate- and continuous vigorous-intensity exercise in the exercise intensity-affect continuum. *PLoS ONE*, *9*(12), e114541. https://doi.org/10.1371/journal.pone.0114541

Keir, D.A., Fontana, F.Y., Robertson, T.C., Murias, J.M., Paterson, D.H., Kowalchuk, J.M., & Pogliaghi, S. (2015). Exercise intensity thresholds: Identifying the boundaries of sustainable performance. *Medicine and Science in Sports and Exercise*, *47*(9), 1932-1940. https://doi.org/10.1249/MSS.0000000000000613

Khoramipour, K., Gaeini, A.A., Shirzad, E., Gilany, K., Chashniam, S., & Sandbakk, Ø. (2021). Metabolic load comparison between the quarters of a game in elite male basketball players using sport metabolomics. *European Journal of Sport Science*, *21*(7), 1022-1034. https://doi.org/10.1080/17461391.2020.1805515

Kokkinos, P.F., Faselis, C., Myers, J., Narayan, P., Sui, X., Zhang, J., …, & Fletcher, R. (2017). Cardiorespiratory fitness and incidence of major adverse cardiovascular events in US veterans: A cohort study. *Mayo Clinic Proceedings*, *92*(1), 39-48. https://doi.org/10.1016/j.mayocp.2016.09.013

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Lässing, J., Maudrich, T., Kenville, R., Uyar, Z., Bischoff, C., Fikenzer, S., …, & Falz, R. (2023). Intensity-dependent cardiopulmonary response during and after strength training. *Scientific Reports*, *13*(1), 6632. https://doi.org/10.1038/s41598-023-33873-x

Lee, S., Choi, Y., Jeong, E., Park, J., Kim, J., Tanaka, M., & Choi, J. (2023). Physiological significance of elevated levels of lactate by exercise training in the brain and body. *Journal of Bioscience and Bioengineering*, *135*(3), 167-175. https://doi.org/10.1016/j.jbiosc.2022.12.001

Legaz-Arrese, A., Munguía-Izquierdo, D., Carranza-García, L.E., & Torres-Dávila, C.G. (2011). Validity of the Wingate anaerobic test for the evaluation of elite runners. *Journal of Strength and Conditioning Research*, *25*(3), 819-824. https://doi.org/10.1519/JSC.0b013e3181c1fa71

Löllgen, H., & Leyk, D. (2018). Exercise testing in sports medicine. *Deutsches Ärzteblatt International*, *115*(24), 409-416. https://doi.org/10.3238/arztebl.2018.0409

Manoelles, P. (2005). *Cardiología del deporte*. Nexus Médica.

Manonelles P., Franco L., & Naranjo, J. (2016). Pruebas de esfuerzo en medicina del deporte Documento de consenso de la Sociedad Española de Medicina del Deporte (SEMED-FEMEDE). [Stress tests in sports medicine. Consensus document of the Spanish Society of Sports Medicine (SEMED-FEMEDE).] *Archivos de Medicina del Deporte*, *33*(Suppl. 1), 1-86.

Maron, B.J., Haas, T.S., Ahluwalia, A., Murphy, C.J., & Garberich, R.F. (2016). Demographics and epidemiology of sudden deaths in young competitive athletes: From the United States National Registry. *The American Journal of Medicine*, *129*(11), 1170-1177. https://doi.org/10.1016/j.amjmed.2016.02.031

Marszałek, J., Kosmol, A., Morgulec-Adamowicz, N., Mróz, A., Gryko, K., Klavina, A., …, & Molik, B. (2019). Laboratory and non-laboratory assessment of anaerobic performance of elite male wheelchair basketball athletes. *Frontiers in Psychology*, *10*, 514. https://doi.org/10.3389/fpsyg.2019.00514

McInnes, S.E., Carlson, J.S., Jones, C.J., & McKenna, M.J. (1995). The physiological load imposed on basketball players during competition. *Journal of Sports Sciences*, *13*(5), 387-397. https://doi.org/10.1080/02640419508732254

Medbø, J.I., & Toska, K. (2001). Lactate release, concentration in blood, and apparent distribution volume after intense bicycling. *The Japanese Journal of Physiology*, *51*(3), 303-312. https://doi.org/10.2170/jjphysiol.51.303

Mehra, M., Kobashigawa, J., Starling, R., Russell, S., Uber, P., Parameshwar, J., …, & Barr, M. (2006). Listing criteria for heart transplantation: International Society for Heart and Lung Transplantation guidelines for the care of cardiac transplant candidates—2006. *The Journal of Heart and Lung Transplantation*, *25*(9), 1024-1042. https://doi.org/10.1016/j.healun.2006.06.008

Morentin, B., Suárez-Mier, M.P., Monzó, A., Ballesteros, J., Molina, P., & Lucena, J. (2021). Muerte súbita relacionada con la actividad deportiva en España. Estudio poblacional multicéntrico forense de 288 casos. [Sports-related sudden cardiac death in Spain. A multicenter, population-based, forensic study of 288 cases.] *Revista Española de Cardiología*, *74*(3), 225-232. https://doi.org/10.1016/j.recesp.2020.05.035

Myers, J., Arena, R., Franklin, B., Pina, I., Kraus, W.E., McInnis, K., & Balady, G.J. (2009). Recommendations for clinical exercise laboratories: A scientific statement from the American Heart Association. *Circulation*, *119*(24), 3144-3161. https://doi.org/10.1161/CIRCULATIONAHA.109.192520

Petway, A.J., Freitas, T.T., Calleja-González, J., Medina Leal, D., & Alcaraz, P.E. (2020). Training load and match-play demands in basketball based on competition level: A systematic review. *PLoS ONE*, *15*(3), e0229212. https://doi.org/10.1371/journal.pone.0229212

Pinkstaff, S., Peberdy, M.A., Kontos, M.C., Finucane, S., & Arena, R. (2010). Quantifying exertion level during exercise stress testing using percentage of age-predicted maximal heart rate, rate pressure product, and perceived exertion. *Mayo Clinic Proceedings*, *85*(12), 1095-1100. https://doi.org/10.4065/mcp.2010.0357

Quittmann, O.J., Schwarz, Y.M., Mester, J., Foitschik, T., Abel, T., & Strüder, H.K. (2021). Maximal lactate accumulation rate in all-out exercise differs between cycling and running. *International Journal of Sports Medicine*, *42*(04), 314-322. https://doi.org/10.1055/a-1273-7589

Rabadán, M., & Boraita, A. (2005). Las pruebas de esfuerzo en la valoración cardiológica y funcional del deportista.

In *Cardiología del deporte* (pp. 79-123). Barcelona: Nexus Médica.

Remor, E. (2006). Psychometric properties of a European Spanish version of the Perceived Stress Scale (PSS). *The Spanish Journal of Psychology*, *9*(1), 86-93. https://doi.org/10.1017/S1138741600006004

Sánchez Arjona, C., Ruiz Martínez, Y., & Martín Fernández, M.C. (2008). Influencia del lugar de extracción en la determinación de los niveles de lactato durante una prueba de esfuerzo incremental. [Influence of the extraction place in the determination of lactate levels during a test of incremental exercise.] *Revista Andaluza de Medicina del Deporte*, *1*(2), 57-60.

Sánchez-Beleña, F., & García-Naveira Vaamonde, A. (2017). Sobreentrenamiento y deporte desde una perspectiva psicológica: Estado de la cuestión. [Overtraining and sports from a psychological perspective: The state of the question.] *Revista de Psicología Aplicada al Deporte y el Ejercicio Físico*, *2*(2), e12. https://doi.org/10.5093/rpadef2017a8

Sanders, G.J., Boos, B., Rhodes, J., Kollock, R.O., & Peacock, C.A. (2021). Competition-based heart rate, training load, and time played above 85% peak heart rate in NCAA Division I women's basketball. *Journal of Strength and Conditioning Research*, *35*(4), 1095-1102. https://doi.org/10.1519/JSC.0000000000002876

Sansone, P., Gasperi, L., Tessitore, A., & Gomez, M. (2021). Training load, recovery and game performance in semiprofessional male basketball: Influence of individual characteristics and contextual factors. *Biology of Sport*, *38*(2), 207-217. https://doi.org/10.5114/biolsport.2020.98451

Santos, L., González, V., Iscar, M., Brime, J.I., Fernández-Río, J., Rodríguez, B., & Montoliu, M.A. (2012). Physiological response of high-level female judokas measured through laboratory and field tests. Retesting the validity of the Santos test. *The Journal of Sports Medicine and Physical Fitness*, *52*(3), 237-244.

Sawada, Y., Ichikawa, H., Ebine, N., Minamiyama, Y., Alharbi, A.A.D., Iwamoto, N., & Fukuoka, Y. (2023). Effects of high-intensity anaerobic exercise on the scavenging activity of various reactive oxygen species and free radicals in athletes. *Nutrients*, *15*(1), 222. https://doi.org/10.3390/nu15010222

Stojanović, E., Stojiljković, N., Scanlan, A.T., Dalbo, V.J., Berkelmans, D.M., & Milanović, Z. (2018). The activity demands and physiological responses encountered during basketball match-play: A systematic review. *Sports Medicine*, *48*(1), 111-135. https://doi.org/10.1007/s40279-017-0794-z

Takahashi, H., Yoshika, M., & Yokoi, T. (2015). Validation of three automatic devices for the self-measurement of blood pressure according to the European Society of Hypertension International Protocol revision 2010: The Omron HEM-7130, HEM-7320F, and HEM-7500F. *Blood Pressure Monitoring*, *20*(2), 92-97. https://doi.org/10.1097/MBP.0000000000000096

Warr-di Piero, D., Valverde-Esteve, T., Redondo-Castán, J.C., Pablos-Abella, C., & Sánchez-Alarcos Díaz-Pintado, J.V. (2018). Effects of work-interval duration and sport specificity on blood lactate concentration, heart rate and perceptual responses during high intensity interval training. *PLoS ONE*, *13*(7), e0200690. https://doi.org/10.1371/journal.pone.0200690

Weichenberger, M., Esefeld, K., & Müller, S. (2023). Kardiopulmonale Leistungsdiagnostik beim Spitzensportler. [Exercise testing in top athletes.] *Herzschrittmachertherapie + Elektrophysiologie*, *34*, 19-25. https://doi.org/10.1007/s00399-022-00916-1

Wilson, D.F. (2016). Regulation of metabolism: The work-to-rest transition in skeletal muscle. *American Journal of Physiology—Endocrinology and Metabolism*, *310*(8), E633-E642. https://doi.org/10.1152/ajpendo.00512.2015

Wu, J., Han, X., Sun, D., Zhang, J., Li, J., Qin, G., …, & Xu, H. (2023). Age-specific association of stage of hypertension at diagnosis with cardiovascular and all-cause mortality among elderly patients with hypertension: A cohort study. *BMC Cardiovascular Disorders*, *23*(1), 270. https://doi.org/10.1186/s12872-023-03250-7

Yanci, J., Granados, C., Otero, M., Badiola, A., Olasagasti, J., Bidaurrazaga-Letona, I., …, & Gil, S. (2014). Sprint, agility, strength and endurance capacity in wheelchair basketball players. *Biology of Sport*, *32*(1), 71-78. https://doi.org/10.5604/20831862.1127285

Yang, P., Jang, E., Yu, H.T., Kim, T., Pak, H., Lee, M., & Joung, B. (2021). Changes in cardiovascular risk factors and cardiovascular events in the elderly population. *Journal of the American Heart Association*, *10*(11), e019482. https://doi.org/10.1161/JAHA.120.019482

Submitted: May 8, 2024
Accepted: September 30, 2024
Published Online First: December 23, 2024

Correspondence to:
Jose Vicente Beltran-Garrido, Ph.D.
Department of Education Science
School of Humanities and Communication Sciences,
CEU-Cardenal Herrera University,
12006 Castellón de la Plana, Spain
Email: josevicentebelga@gmail.com

THE EFFECTS OF THE OPPOSITION ON COLLECTIVE AND INDIVIDUAL BEHAVIOURS IN SOCCER: A SYSTEMATIC REVIEW

Victor Reis Machado, João Marcelo Niquini Caríssimo, and Israel Teoldo
Centre of Research and Studies in Soccer (NUPEF) – Universidade Federal de Viçosa, Viçosa, Brazil

Systematic review
DOI 10.26582/k.56.2.15

Abstract:

Opposition in soccer is a determining factor for the success of collective and individual actions that are performed by the players to solve the problems of the game. Many studies studied the opposition in official matches and training and its impact on the dimensions of soccer. However, no previous review organised the literature about the effects of the opposition in soccer training. Therefore, this systematic review aimed to verify: i) the effects of the opposition in individual and collective behaviours in soccer training; ii) how was the level of the opposition established during training; and iii) how the variables were analysed and instruments utilized to measure those effects. The PRISMA guidelines were used to search five databases for relevant publications before 10th April 2023. The population was soccer players, and the outcome was any variable related to the tactical, technical, physical, and/or psychological dimension. In the end, there were thirteen studies included. Overall, the main results pointed out two ways to establish the opposition in soccer training: numerical relations and through teams' composition according to players' individual characteristics. Moreover, it is possible to affect soccer's tactical, technical, and physical dimensions by establishing the opposition in different ways. Manipulating the opposition through numerical relationships can facilitate the exchange of passes and maintenance of ball possession, in the offensive phase, and generate greater commitment in attempts to recover possession of the ball in the defensive phase. Regarding the individual characteristics of the players, the effects of the opposition depend mainly on the variable used in organising the teams.

Key words: *football, training sessions, small-sided games, decision-making, tactics*

Introduction

Soccer is dynamic, fluid, and complex (Garganta & Gréhaigne, 1999). It is characterised by the simultaneous existence of cooperation and opposition, which causes at every moment a collective relational dynamics that stimulates players to evaluate game situations and make constant decisions based on actions, reactions, and interactions; the said build the singularity and diversity of the flow of events that allow goals to be scored in the opponent's goal and prevent conceding a goal in one's own goal (Castelo, 1996; Júlio & Araújo, 2005). In this context, according to the theory of dynamic systems, the two teams involved in a match are seen as two interacting systems in motion, in which the quality of the opposition is a determining factor for the success of the interactions and, consequently, for the collective and individual actions that are performed to solve the problems of the game thus allowing the achievement of the main goal (Gréhaigne & Godbout, 2014).

The opposition (namely: level of opposition, quality of opposition, and ability of opposition) in soccer has been primarily studied in official match situations. Such studies define the level of the opposition through the opponent's ranking and employ several methods of performance analysis to understand its effects, separately or in conjunction with other situational factors (e.g., match outcome, match venue, match statistics, etc.), on many variables in the game (Lago-Peñas, 2009; Taylor, Mellalieu, James, & Shearer, 2008; Yi, Gómez, Liu, & Sampaio, 2019). The results of these studies indicate that the opposition has a direct effect on variables related to the tactical (Fernandez-Navarro, Fradua, Zubillaga, & McRobert, 2018), technical (Augusto, et al., 2022), and physical dimensions (Aquino, et al., 2020). Therefore, the opposition plays a central role in the team's performance during official matches and should be considered during the teams' preparation.

Furthermore, the other context in which the opposition has been studied in soccer regards training sessions. In this sense, the level of the opposition is usually a task constraint that can be manipulated in small-sided games (SSG) (Práxedes, Moreno, Gil-Arias, Claver, & Del Villar, 2018) and is understood as the level of difficulty presented due to the numerical equality or inequality of the participating teams (Travassos, et al., 2012; Travassos, Vilar, Araújo, & McGarry, 2014). This concept is directly related to the general tactical principles, which are based on the numerical and spatial relationships between teammates and opponents in the ball contention zones (Garganta & Pinto, 1994; Teoldo, Guilherme, & Garganta, 2021). In this regard, it was found that the level of the opposition can impact the tactical (Gonçalves, Marcelino, Torrents, & Sampaio, 2016), technical (Práxedes, Pizzaro, Travassos, Dominguez, & Moreno, 2021), and physical dimensions (Torres-Ronda, et al., 2015) in soccer training. Those results are similar to the findings of studies with official matches, and they must have this congruence once the training process aims to improve the skills and competencies of players and teams to meet the competitive demands required (Teoldoet al., 2021).

While many studies comprise the opposition in a competitive context of soccer (Aquino, et al., 2020; Augusto, et al., 2022; Fernandez-Navarro, et al., 2018), the number of studies that include the opposition in training sessions is much smaller. Even being an intrinsic element to the soccer game, it is commonly manipulated during training (Práxedes, et al., 2018), researchers have dedicated so much effort to studying the manipulation of other parameters like the number of players and field dimensions (Ometto, et al., 2018) instead of the opposition. A possible explanation for this fact may be related to the difficulty of establishing and controlling the opposition in training in an effective way since the same parameter in official matches could be easily associated with the ranking of the opposite team.

Despite the aforementioned importance of the opposition in both contexts (e.g., official matches and training sessions) in soccer, to the best of our knowledge, no previous review has been conducted investigating the influence of the level of the opposition on training sessions in soccer. It is essential to understand how coaches establish and manipulate the opposition to ensure adequate training to generate behaviours that meet the demands imposed by the opponent during the match. In addition, it is necessary to know the variables analysed and instruments utilized to understand how individual and collective behaviours change according to the level of the opposition in this situation. Therefore, this article aims to systematically review the literature to verify: i) the effects of the opposition on individual and collective behaviours in soccer training, ii) how was the level of the opposition established during training sessions; and iii) how were the variables analysed, and what instruments utilized to measure those effects.

Materials and methods

Search strategy and inclusion criteria

A systematic review of the available literature on the effects of the opposition in soccer was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page, et al., 2021). The protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols with the number 202340105 and the DOI number 10.37766/inplasy2023.4.0105. The Population, Intervention, Comparison, Outcome (PICO) framework was adapted and employed to develop the search strategy. The population of interest was soccer players. The intervention was the opposition. No comparison was used because the review sought to investigate what interventions have been carried out on this topic. The outcome was any tactical, technical, physical, or psychological variable.

In order to ensure article quality, five databases were used for the search: 1) Web of Science (all databases); 2) SCOPUS; 3) PubMed; 4) SPORTDiscuss; and 5) Scielo. The search was carried out for relevant publications prior to 10th April 2023. The title, abstract, and keywords were searched through the following descriptors: [(soccer OR football) AND (opposition OR opponent OR "quality of opposition" OR "levels of opposition" OR "situational variables" OR "contextual variables" OR "opposition ability" OR "numerical unbalance" OR "opposing teams") NOT (referee OR injur* OR "american football" OR "australian football" "gaelic football" OR rugby OR volleyball OR basketball OR "robot soccer" OR handball)].

The inclusion criteria for the articles were: 1) published in peer-reviewed scientific journals; 2) the study was carried out with male or female soccer players (either youth or adult); 3) written in the English, Portuguese, or Spanish language. On the other hand, the exclusion criteria were applied if the article: 1) was related to any other sport different from soccer; 2) was a review, opinion, or a conference abstract; and 3) was a study in the context of friendly or official match; 4) was a study classified as having low methodological quality (≤ 50%). In case of any disagreement, it was solved by discussion between the two review authors (VM and JMC).

Two independent reviewers (VM and JMC) separately screened titles and abstracts to identify articles based on the inclusion criteria. For those articles, full text was screened by those reviewers to establish whether the inclusion criteria were met. Disagreements were solved by discussion between the two reviewers.

A backward search was carried out by screening references for those selected articles in databases. Those references that exhaustively matched the inclusion criteria were included in the review.

Extraction of data and quality of the studies

The quality of the studies was assessed with a risk-of-bias quality form (16 items) adapted from Law et al. (1998) and previously used in systematic reviews of sports (Sarmento, Anguera, Pereira, & Araújo, 2018; Sarmento, Clemente, Araújo, Davids, McRoberts, & Figueiredo, 2018; Sarmento, Clemente, Harper, Teoldo, Owen, & Figueiredo., 2018). The items in the form assessed articles based on: objective (item 1); relevance of background literature (item 2); study design (items 3); the sample included (items 4 and 5); informed consent obtention (item 6); outcome measures (items 7 and 8); description of methods (item 9); results significance (item 10); analysis methods (item 11); practical importance (item 12); drop-outs description (item 13); appropriateness of conclusion (item 14); practical implications (item 15); and study limitations (item 16). The assessment for each item was a binary scale (1 – meets the criteria; 0 – does not meet the criteria). The quality of the articles was expressed individually as a final score corresponding to the sum of the scores that met the criteria (1) divided by the total number of scored items (16). Articles were classified based on their final scores as having low methodological quality (≤ 50%); good methodological quality (between 51% and 75%), and excellent methodological quality (> 75%), as used in previous studies (Faber, Bustin, Oosterveld, Elferink-Gemser, & Van der Sanden, 2016; Sarmento, Anguera, et al., 2018; Wierike, Van Der Sluis, Van Der Akker-Scheek, Elferink-Gemser, & Visscher , 2013).

A data extraction sheet was used (adapted from Cochrane Consumers and Communication Review Group's data extraction template). Initially, one of the researchers assessed the studies included in this review, and the second researcher checked the inputted data (VM and JMC). Any disagreement was solved by the consensus between both researchers.

Narrative analysis was used to synthesise and analyse the information collected from each included publication. This approach involved the grouping of studies according to the establishment of the opposition.

Results

Search, selection, and inclusion of publications

Initially, 4507 articles were found in the aforementioned databases. All these articles were exported to the reference software manager (EndNote 20.0). In the next step, all duplicates (n = 1550) were removed manually and automatically. Afterwards, the remaining 2957 articles were screened for relevance based on their title and abstract, resulting in the exclusion of 2825 articles. The remaining 132 articles were eligible to the screening based on their full text, but four were excluded because the full text was not found, resulting in the full-text screening of the remaining 128 articles. There were 115 articles excluded based on the inclusion/exclusion criteria, leaving 13 articles for in-depth reading and analysis. The main reasons for exclusion are described in the flow chart (see Figure 1). Subsequently, a backward search based on the references from those 13 selected articles was performed, but not any other article was included for consideration. In total, 13 articles were reviewed in this paper. The chronological analysis of the articles included in this review showed that the selected articles were published between 2015 and 2023. Furthermore, all articles (100%) included in this review were published in the last ten years.

Quality of the studies

Considering the quality of the studies (see Table 1), the main results were: 1) The average score for methodological quality of the thirteen included articles was 83.7%; 2) 11 (84.6%) articles achieved an excellent methodology quality (>75%); 3) two (15.4%) articles achieved a good methodology quality (between 51% and 75%); and 4) the 13 included articles achieved an overall score of > 75% (excellent methodology quality).

Some possible limitations of the 13 selected articles were found, which were related to three items assessed and are further described in order of percentage: 1) item 13 – the totality of studies (n = 13; 100%) did not inform about drop-outs; 2) item 5 – the majority of studies (n = 12; 92.3%) did not justify the sample size; and 3) item 16 – more than a half of the studies (n = 7; 53.8%) did not acknowledge and/or describe the limitations.

Data extraction and synthesis

The characteristics of the thirteen studies included in this systematic review are presented in Table 1. Overall, the effects of the opposition on collective and individual behaviours in soccer training were verified in all thirteen studies (100%). Additionally, according to the aims of this study and

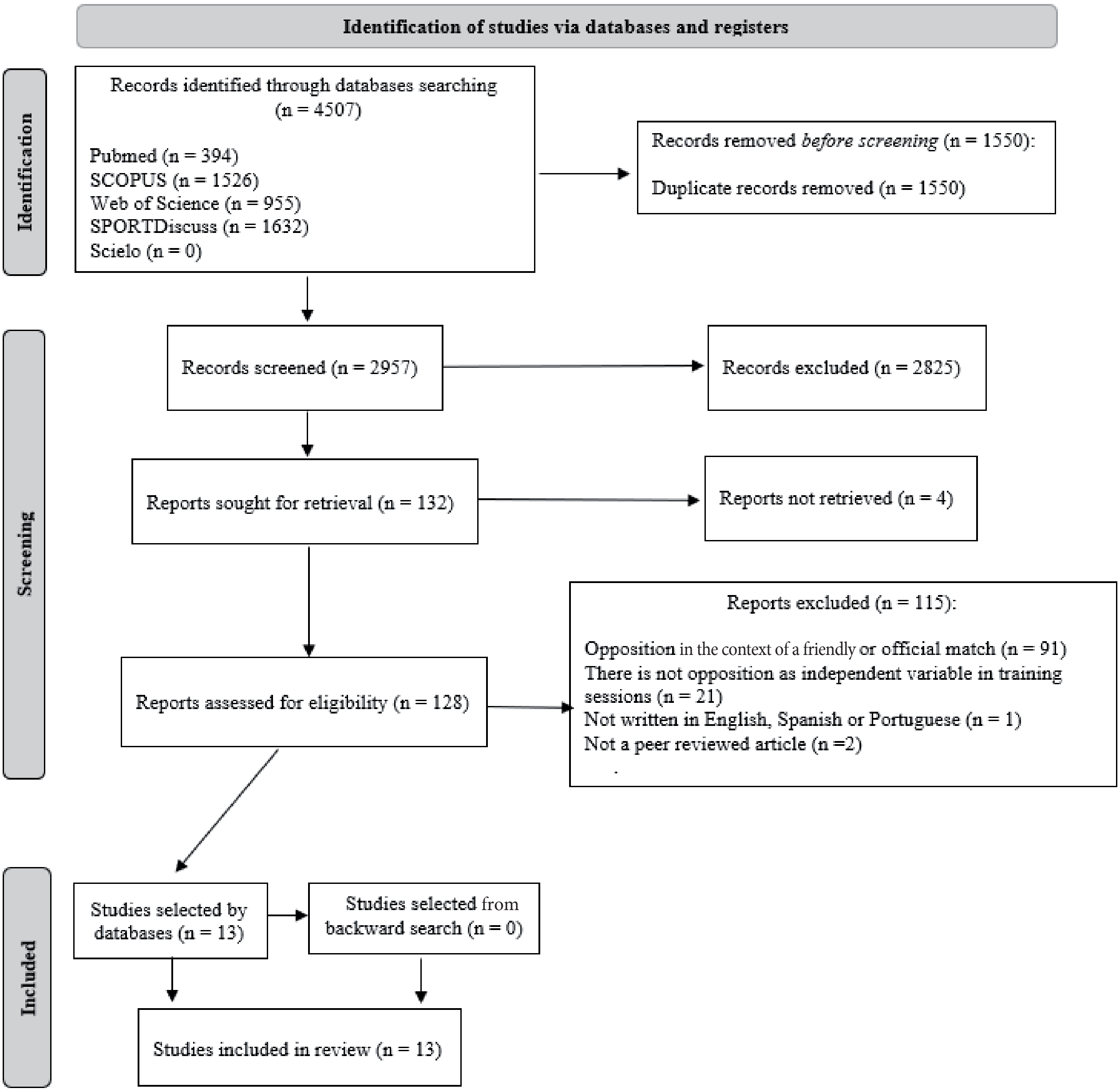


Figure 1. Flow chart of the methodology used for the article search based on the preferred reporting items for systematic review (PRISMA).

for a better understanding of the data, the results will be presented separately according to the establishment of the opposition and the measurements realised.

Opposition establishment

In terms of the establishment of the opposition in the thirteen studies, the great majority used numerical relations (numerical superiority/inferiority) (n = 10), followed by teams' composition according to players' individual characteristics (n = 3). Regarding players' individual characteristics, all studies (n = 3) have used different characteristics: creative behaviour (n = 1), procedural tactical knowledge (n = 1), and experts' subjective evaluation (n = 1).

Measurements

The 13 studies included in this review have analysed three of the four possible dimensions of soccer: the majority (n = 10) have assessed the tactical dimension, followed by the physical (n = 7) and finally, the technical (n = 4). None of the studies have assessed the psychological dimension.

Regarding the tactical dimension (n = 10), which was the most frequently studied, it was found that the majority of the articles analysed this dimension in conjunction with the physical (n = 4) followed by the analysis of the technical dimension (n = 3) and the tactical dimension separately (n = 3). Concerning the variables related to the tactical dimension, it was found that a significant number of studies (n = 5) has used individual tactical behaviours

Table 1. Studies that investigated the effects of opposition in soccer

Article Information		Aim	Participants Information	Game Information		Opposition establishment	Measurements			Main Evidence
Authors (Year)	Quality			Game Format	Pitch Dimensions		Soccer dimension assessed	Variables	Instruments	
Santos *et al.* (2023)	87.50	The purpose of this study is to identify the creative and tactical effects of playing against a varying number of creative opponents (1C, 2C, 2C and 4C) of different age groups (U9, U11 and U13) during youth football Small-sided games.	60 male young players (20 U9, 20 U11 and 20 U13)	• GK + 4 x 4 + GK	• 40 x 30	Number of creative players according to Creative Behaviour Assessment in Team Sports (CBATS) (Santos *et al.*, 2017)	• Tactical	Tactical behaviours: spartial exploration index, distance to team centroid (absolute value, coefficient of variation and approximate entropy), and distance to opponent centroid (absolute value, coefficient of variation and approximate entropy)	GPS (SPI-PRO, GPSports, Canberra, ACT, Australia)	The results showed that U9 players increased the individual space explored when facing more creative opponents, while U11 and U13 only increased when facing 2C and 3C. Playing against more creative opponents induced more variability in the distance to own and the opponent team's centroid in U9, regularity in U11 and lower regularity in U13. From the creative behaviour analysis, statistically significant differences were found in the creative behaviour scores of U9 players, with higher values against 1C than for the remaining conditions primarily when compared with 4C. These results indicate that this age group is more sensitive to changes in the opposing team from the creative behaviour perspective
Práxedes *et al.* (2022)	87.50	The main purpose of this study was to understand the effect of the use of a task of numerical superiority in attack (5 x 4) before a task of equal number of player in comparison with the use of only two numerical equality (5 x 5) tasks. A second objective was to examine this effect according to the game principles: keep the ball possession and progress to the goal.	20 male young players (U14)	• 5 x 4 • 5 x 5	• 40 x 25	Numerical Relation	• Tactical • Technical	Decision-making (pass and dribbling actions), number of ball touches and the duration of ball possession	Game Performance Evaluation Tool (GPET) (García-López *et al.*, 2013) and Notational Analysis	Results show a tendency to decrease the offensive performance in the sequence (Numerical superiority + Numerical equality). However, if we compare both initial situations, significant higher values were observed in the situation with numerical superiority. In addition, regarding the two final situations, there are hardly any differences between them.
Nunes *et al.* (2021)	75.00	This study aimed to examine the effects of age group (U11, U15, and U23) on the external, internal workloads, and tactical individual actions when playing 4 x 2, 4 x 4, and 4 x 6 ball possession small-sided soccer games.	52 male young and amateur players (16 U11, 18 U15, and 18 U23)	• 4 x 2 • 4 x 4 • 4 x 6	• 30 x 25	Numerical Relation	• Tactical • Physical	External workload: total distance covered (m), distance differentiated by walking (≤9 km/h), running (9–18 km/h) and sprinting (>18 km/h), number of sprints (n), maximum sprint speed (km/h); Internal workload; and tactical individual actions: number of passing with the dominant and non-dominant foot (n), and maximum passing speed (km/h)	GPS (ZEPP Play Soccer system, ZEPP Labs, San Jose, United States) and RPE Borg Scale CR10 (Borg, 1982)	From an opposition-based perspective, older age groups covered longer distances while walking and perceived the task as more intense for all game formats, whereas the younger age groups did this while sprinting. The 4 x 2 promoted more passes and the 4 x 6 constrained speed of ball circulation for U11.
Nunes *et al.* (2021)	87.50	The aim of this study was to evaluate the effects of the unbalanced number of players (4 x 3, 4 x 4 and 4 x 5) in ball possession SSGs on U23 football players' performance, in three different playing areas (small: 20x15, medium: 25 x 20, and large: 30 x 25), under perspectives of opposition and cooperation.	23 male amateur players (U23)	• 4 x 3 • 4 x 4 • 4 x 5	• 20 x 15 • 25 x 20 • 30 x 25	Numerical Relation	• Tactical • Physical	External workload: total distance covered (m), distance differentiated by walking (≤9 km/h), running (9–18 km/h) and sprinting (>18 km/h), number of sprints (n), maximum sprint speed (km/h); Internal workload; and tactical individual actions: number of passing with the dominant and non-dominant foot (n), and maximum passing speed (km/h)	GPS (ZEPP Play Soccer system, ZEPP Labs, San Jose, United States) and RPE Borg Scale CR10 (Borg, 1982)	From an opposition-based perspective, the higher the number of players involved in the task, the more significant differences are found in terms of external load. In terms of space manipulation, it is well reported that playing area dimensions influence the intensity of the game, the actions of the players and the energy systems used with large playing areas associated with an increase in the intensity of exercise. Furthermore, this improvement in the physical demands was more evident when playing against a higher number of opponents (4 x 5).

Table 1. (continued)

Article Information		Aim	Participants Information	Game Information		Opposition establishment	Measurements			Main Evidence
Authors (Year)	Quality			Game Format	Pitch Dimensions		Soccer dimension assessed	Variables	Instruments	
Nunes *et al.* (2020)	87.50	This study aimed to explore the effects of playing different unbalanced ball possession small-sided games on external workload (distance covered while walking, running, and sprinting, and max speed), tactical individual actions (number of passes with dominant and non-dominant foot), and internal load (rating of perceived exertion, RPE) in U23 soccer players.	20 male amateur players (U23)	• 4 x 2 • 4 x 3 • 4 x 4 • 4 x 5 • 4 x 6	• 30 x 25	Numerical Relation	• Tactical • Physical	External workload: total distance covered (m), distance differentiated by walking (≤9 km/h), running (9–18 km/h) and sprinting (>18 km/h), number of sprints (n), maximum sprint speed (km/h); Internal workload; and tactical individual actions: number of passing with the dominant and non-dominant foot (n), and maximum passing speed (km/h)	GPS (ZEPP Play Soccer system, ZEPP Labs, San Jose, United States) and RPE Borg Scale CR10 (Borg, 1982)	From an opposition-based perspective, 4 x 2 and 4 x 3 conditions allow players to walk more, while 4 x 6 causes players to sprint longer distances. Player behavior adapts to the number of players involved during small-sided games: when players are in numerical superiority, they can use the available space and the team's playing area dispersion to facilitate ball possession; on the other hand, when players are in numerical inferiority, they need to increase intensity levels and perform in coordination with their teammates to recover ball possession.
Ibáñez *et al.* (2020)	87.50	The purposes of this study were to identify which major constraints contribute to greater task workload and to determine distinctive training task profiles using an integrative approach during a regular season from a professional women's soccer team.	27 female professional players (Adult)	-	-	Numerical Relation	• Physical	Total Task Workload	SIATE (Sistema Integral para el Análisis de las Tareas de Entrenamiento) integrative tool assessment (Ibáñez et al., 2016); HR telemetric systems Suunto Team Manager 2.1.2® and Suunto Team Monitor 2.1.1® and Yo-Yo Intermittent Recovery Test Level 1 (Krustrup et al., 2005)	Task constraints contribute differently to the total workload in professional women's soccer team. The constraints that most affected the total task workload were the interaction possibilities, competitive workload, opposition degree and simultaneous participation.
Práxedes *et al.* (2018)	87.50	The objective of this study was to analyze the effect of two teaching programs, each utilizing modified games with varied levels of opposition, on decision-making and action execution in young players with different levels of sports expertise.	19 male young players (U12:10 average level skill players, and 9 low level skill players)	• 3 x 2 • 3 x 3 • 4 x 3 • 4 x 4 • 5 x 4 • 5 x 5	• 30 x 15 • 35 x 20 • 40 x 25	Numerical Relation	• Tactical • Technical	Decision-making (successful decision/decisions made) and execution (% successful execution/executions made) of the passes	Game Performance Evaluation Tool (GPET) (García-López et al., 2013)	For average level players: the numerical superiority program has improved decision-making and skill execution. For low level players: only the skill execution. For both groups: the numerical equality program has not improved anything.
Torrents *et al.* (2016)	81.25	The aim of this study was to examine how the constraints such as number of opponents and teammates affect the technical, tactical, and exploratory behavior in small-sided games, in both professional and amateur players.	44 male adult players (22 professionals and 22 amateurs)	• GK + 4 x 3 + GK • GK + 4 x 5 + GK • GK + 4 x 7 + GK	• 40 x 30	Numerical Relation	• Tactical • Technical	Tactical/Technical actions: attacker with the ball (run to the ball, wait, control, pass, shoot, protect, drive, feint, dribble, intercept, deflect, clear, anticipate); attackers without the ball (wait, support, unmark); and defenders (press, delay, dissuade, balance, withdraw)	Observational instrument based on (Owen *et al.*, 2014; and Teoldo *et al.*, 2011)	An increase in the number of opponents produced an increase of the frequency of defensive patterns and, especially, an increase in the number of players controlling and a decrease in the number of players waiting. In addition, an increase in the number of opponents also produced a decrease in the use of basic actions such as passing or driving by players in possession of the ball. In terms of the emergence of flexible and fluent behavior, players seem to show more exploratory behavior when playing with a numerical disadvantage. The effect of the three small-sided games formats seems to be similar for both amateur and professional players.
Ric *et al.* (2016)	87.50	The aim of this study was to identify the dynamics of tactical behaviour emerging on different timescales in football small-sided games and to quantify short- and long-term exploratory behaviour according to the number of opponents.	80 male professional players (Adult)	• 4 x 3 • 4 x 5 • 4 x 7	• 40 x 30	Numerical Relation	• Tactical	Tactical behaviours (tactical core principles, inter-player contexts, pitch zones and movement speeds) related to timescale: <qstat>, Entropy, Trapping strength	Observational instrument based on (Teoldo *et al.*, 2011; Clemente *et al.*, 2014; and Folgado *et al.*, 2014) and GPS (SPI ProX, GPSports, Canberra, ACT, Australia)	The tactical diversity of the players decreased with the increase in the number of opponents, mainly in defense. Manipulating numerical imbalance will likely promote changes in the diversity, unpredictability, and flexibility of tactical solutions. The fact that the temporally nested structure of constraints shaped the emergence of tactical behavior provides new justification for the design of practical tasks. Manipulating numerical imbalance on the time scale of a few tens of seconds, where players' exploratory behavior saturates, can help coaches optimize the exploratory efficiency of reduced games.

Table 1. (continued)

Article Information		Aim	Participants Information	Game Information		Opposition establishment	Measurements			Main Evidence
Authors (Year)	Quality			Game Format	Pitch Dimensions		Soccer dimension assessed	Variables	Instruments	
Praça *et al.* (2016)	81.25	This study aims to analyze the influence of opponents' changes on the tactical and physical behavior of soccer players during small-sided games.	18 male young players (U17)	• GK + 3 x 3 + GK	• 36 x 27	Procedural Tactical Knowledge according to Teste de Conhecimento Tático Processual (TCTP OE) (Greco *et al.* , 2014)	• Tactical • Physical	Physical demands: Total distance and distances covered by speed zones (total distance covered between 0 and 7.2 km/h, total distance covered between 7.3 and 14.3 km/h, total distance covered between 14.4, and 21.5 Km/h). Accelerations (total acceleration actions from 2 m/s², total distance traveled in accelerations from 2 m/s², total acceleration actions from 2.5 m/s², Total distance traveled in accelerations from 2.5 m/s). Tactical behavior (width, depth, distance between centroids and length per width ratio)	GPS: (SPI Pro, GPSports, Canberra, Australia)	In general, no differences were observed in tactical behavior from changing the opposing teams and few differences were observed on physical demand during small-sided games was reported (only in Total distance covered between 0 and 7.2 km/h and in Total acceleration actions from 2 m/s²).
Gonçalves *et al.* (2016)	81.25	This study is aimed to compare the player positioning dynamics when manipulating the number of opponents and teammates during football small-sided games played by professional and amateur players.	44 male adult players (22 professionals and 22 amateurs)	• 4 x 3 • 4 x 5 • 4 x 7	• 40 x 30	Numerical Relation	• Tactical	Positional variables: effective playing space, distance to centroid (absolut values and approximate entropy), distance to opponent centroid (absolut values and approximate entropy) and distance do nearest opponent (absolut values and approximate entropy)	GPS: (SPI-Pro, GPSports, Canberra, ACT, Australia)	Outcomes suggested that increasing the number of opponents in professional teams resulted in moderate/large decrease in approximate entropy values to both distance to team and opponent team centroid (i.e., the variables present higher regularity/predictability pattern). Increasing the number of opponents was effective to overemphasise the need to use local information in the positioning decision-making process from professionals. Conversely, amateur still rely on external informational feedback.
Torres-Ronda *et al.* (2015)	81.25	The purpose of this study was to determine the internal (heart rate) and external load (body load, distance covered, and exertion index) during different types of unbalanced soccer small-sided games in professional and amateur players.	44 male adult players (22 professionals and 22 amateurs)	• 4 x 3 • 4 x 5 • 4 x 7	• 40 x 30	Numerical Relation	• Physical	Total distance covered, Exertion Index, Body load, Modified traininng impulse and RPE	GPS: (SPI-ProX, GPSports, Canberra, Australia), Heart-rate monitor (1 Hz, Polar Team Sports System, Polar Electro Oy, Finland) and CR10 Borg Scale (Borg, 1982)	Results reveal that the higher the number of players involved in the task, the lower the internal and external workload. The analysis also showed different teammates and opposition related trends that need to be considered when planning and monitoring training performance. Playing in low-inferiority (4 x 3, and 4 x 5) had a higher physiological impact on players than the other higher unbalanced situations. This evidence was similar to both professional and amateur players; however, the professional presented higher physical and lower physiological responses across games.
Hulka *et al.* (2015)	75.00	The purpose of this work is to determine the influence of opponents of different levels on internal response and external load during a 4x4 soccer game.	20 male amateur players (U23)	• GK + 4 x 4 + GK	• 40 x 20	Experts' subjective evaluation	• Physical • Technical	Physical: Heart-rate (average, <75% and 85-90), RPE and distance covered; Technical demands (passes, pass accuracy, shots on goal, steals and turnovers)	TEAM PolarPro System (Kepele, Finland), Observational Tool (Video Manual Motion Tracker 1.0 (Hulka *et al.* , 2014), and RPE Borg Scale CR10 (Borg, 1982)	The results showed significantly lower average heart rate achieved by higher level teams in the 4x4 game against lower level opponents compared to against higher level teams. Then lower level teams reached significantly higher average heart rate in the 4x4 game against higher level teams than in mutual lower level team 4 x 4 game. We found out significantly higher distance covered by lower level teams in 4 x 4 game against higher level teams than in lower level teams mutual 4 x 4 game.

Note. xC : x creative players (e.g., 1 creative player, etc.); Ux : under x (e.g., Under 9; Under 17; etc.); GK : goalkeeper; m : metre; km/h : kilometre per hour; % successful execution/executions made: percentage of successful execution and executions made; n : number; m/s² : metre per second squared; m/s : metre per second; RPE : ratings of perceived exertion; GPS : global positioning system.

(such as tactical core principles and decision-making), followed by the combination of individual and collective tactical behaviours (such as positional variables) (n = 4) and the isolated collective tactical behaviours (n = 1). The instruments employed to assess those variables were Global Positioning System (GPS) (n = 6), observational instruments (n = 3), and a combination of both (n = 1).

In terms of the physical dimension (n = 7), it was found that this dimension was most frequently analysed in addition to the tactical (n = 4) followed by the isolated analysis (n = 2) and jointly the technical (n = 1). Regarding the variables related to the physical dimension, the more significant part of the studies has focused on the combination of external workload (such as total distance covered and total distance covered per speed zones) and internal workload (such as ratings of perceived exertion and heart rate) (n = 4), followed by isolated internal workload (n = 2) and finally the isolated external workload (n = 1). The instruments used in this analysis were: GPS (n = 5), RPE Borg scale (n = 5), and heart-rate monitors (n = 3).

Concerning the technical dimension (n = 4), it was found that a more significant number of studies have analysed it in addition to the tactical dimension (n = 3) followed with the physical dimension in conjunction (n = 1). None of the studies had studied the technical dimension in the isolated form. In terms of analysed variables, half of the studies (n = 2) have analysed just offensive techniques (such as passes and the number of ball touches), and the other half (n = 2) has analysed both offensive and defensive (such as steals and interceptions) techniques. The instruments used in all analyses were observational (n = 4).

Discussion and conclusions

This article aimed to systematically review the literature to verify: i) the effects of the opposition on individual and collective behaviours in soccer training, ii) how was the level of the opposition established during training sessions, and iii) how the variables were analysed and what instruments were utilized to measure those effects. In general, it was found that the opposition affected collective and individual behaviours in soccer training. This result is supported by the main findings of all thirteen studies included in this systematic review. In this sense, as the effects of the opposition are influenced by how the opposition was established, the studies were grouped according to the opposition establishment to highlight and discuss the evidence. Finally, discussion was made about how the opposition establishment met or did not meet the demands of soccer training.

Numerical relations

The studies carried out with the opposition established by numerical relations were the majority included in this systematic review (n = 10), and all of them presented some effect of the opposition on one or more dimensions of the game (namely: tactical, technical, and/or physical). Overall, the findings presented in these studies pointed out that small-sided games played with lower levels of the opposition (numerical superiority) can be used to improve the decision-making and skill execution of the players (Práxedes, et al., 2018), provided a better offensive performance with higher passing frequency and greater ease in keeping ball possession (Nunes, Gonçalves, Roca, & Travassos, 2021; Práxedes, et al., 2021), and resulted in lower physical demands with more covered distances in lower velocity zones (Nunes, Gonçalves, Coutinho, & Travassos, 2020).

One explanation for the results with lower levels of the opposition is that when a team plays in numerical superiority, the players have more time and space to make their decisions and to execute their technical gestures, favouring the development of both decision-making and execution skills, mainly in the average and young players (Práxedes, et al., 2018). Moreover, in numerical superiority, the team generates more uncovered passing lines, which results in a better offensive performance in terms of the number of passes and maintaining the ball possession (Nunes, et al., 2021; Práxedes, et al., 2021). Lastly, due to more time, space, and uncovered passing lines, the players do not need to reach high velocities to generate the passing lines and keep the ball; then, they have more distances covered at lower velocities (Nunes, et al., 2020).

In relation to the training sessions using small-sided games with higher levels of the opposition (numerical inferiority), it was found that the players spent more time in the defensive phase and were more active in trying to recover the ball (Torrents, et al., 2016). Moreover, the players also had higher physiological impacts (Torres-Ronda, et al., 2015). When the team plays in numerical inferiority, it is harder to keep ball possession because the opponent can close out the available space and recover the ball more efficiently, thus it is customary to spend more time in the defensive phase (Torrents, et al., 2016). Since the goal of both teams is the same and is usually fulfilled when in possession of the ball (e.g., keep possession, score a goal), the players in defence have to become more active in trying to regain possession (Torrents, et al., 2016). The physical effort to recover the ball and meet the game objective by compensating for the absence of one or more players, especially in spatial terms having to move more and more quickly to cover the same space, results in greater physiological impact (Torres-Ronda, et al., 2015).

These findings suggest that training with different levels of the opposition affected individual and collective behaviours in soccer players when the opposition is established through numerical relation (Gonçalves, et al., 2016; Ric, et al., 2016). Furthermore, the level of the opposition is a significant factor contributing to the total task load (Ibáñez, Pérez-Goye, García-Rubio, & Courel-Ibáñez, 2020). Thus, it is crucial to understand the effects of this manipulation to better design training sessions according to the aims.

Teams' composition according to players' individual characteristics

In addition to the numerical relations, another way to establish the opposition found in the literature was teams' composition according to players' individual characteristics, which included three studies in this systematic review. In this sense, the three studies have used different parameters to establish the opposition (Hůlka, Weisser, Bělka, & Háp, 2015; Praça, et al., 2016; Santos, Coutinho, Gonçalves, & Sampaio, 2023).

A study by Hůlka and colleagues (2015), which established the opposition through the experts' subjective evaluation, found that lower-level teams achieved higher heart rates and covered longer distance when facing higher-level opponents in 4-a-side SSG. Additionally, higher-level teams reached higher heart rates playing against higher-level opponents than their lower-level counterparts. These results are in accordance with the results from studies using numerical relations, which found that higher levels of the opposition results in superior physiological impacts (Nunes, et al., 2020), even using different parameters to establish the opposition. A possible explanation for these facts could be that higher-level teams displayed superior tactical and technical capacities when evaluated by the experts and converted this superiority by imposing difficulties on the lower-level teams, resulting in higher physical demands imposed on the latter (Hůlka, et al., 2015).

On the other hand, a study conducted by Praça and colleagues (2016), which established the opposition through the procedural tactical knowledge (PTK) (Greco, Campos Aburachid, Da Silva, & Perez Morales, 2014) in 3-a-side games found that teams facing similar levels of the opposition (e.g., lower-level team x lower-level team and higher-level team x higher level team) presented no differences in collective tactical behaviours and just slight differences in physical demands. Therefore, the fact that the teams had similar tactical levels, according to the PTK, could explain the results of collective tactical behaviours (Praça, et al., 2016). On the other hand, the slight differences in physical demands may be related to the fact that, in this study, the players' physical capacities were not controlled when the teams were divided (Praça, et al., 2016). These results partially agree with the results of Hůlka and colleagues (2015), that pointed out no significant differences in physical demands in games with teams of similar levels, especially lower-level teams facing lower-level opponents.

Finally, a study by Santos and colleagues (2023) aimed to identify the creative and tactical effects of playing against a varying number of creative opponents (from one to four creative players) of different age groups (U9, U11, and U13) during 4-a-side SSG. The players' creative behaviour score was assessed using the Creative Behaviour Assessment in Team Sports (CBATS) (Santos, Jimeénez, Sampaio, & Leite, 2017). In general, all categories were affected by the changes in opposing teams from a creative perspective in terms of collective tactical behaviour and creative behaviour (Santos, et al., 2023). Additionally, the players that were more sensitive to these changes were the younger ones (U9) (Santos, et al., 2023). A possible explanation for these findings is that adding more creative players to the opponent team demanded different solutions to the game problems, resulting in a change of collective tactical behaviour and even creative behaviour from the average players (Santos, et al., 2023).

Overall, these results suggest that it is possible to manipulate the levels of the opposition through experts' subjective evaluation to affect physical demands (Hůlka, et al., 2015) and that manipulating levels of the opposition through the creative perspective affected the collective tactical behaviours of young soccer players during training (Santos, et al., 2023). However, using PTK to establish the opposition does not affect collective tactical behaviours and only has minor effects on physical demands (Praça, et al., 2016).

Opposition establishment

As previously mentioned, the opposition establishment is primordial to the studies' findings in this systematic review. Consequently, it is essential to go beyond the discussion of the results themselves by presenting the discussion of the ways of establishing the opposition and exploring their vantages and disadvantages to seek progress in the scientific area and in the practice of soccer training.

In this sense, the opposition level established through numerical relation is directly related to the general tactical principles, which received this name because they are common to the different phases of play and the other categories of principles (Teoldo, Silva, Greco, & Mesquita, 2009). The tactical principles aim to help the players understand the game's logic and solve the game's problems (Teoldo, et al., 2021; Teoldo, et al., 2009). Therefore, it is important to base training processes in soccer, especially tactical training, on tactical principles. Furthermore, tactical training through tactical principles advocates that teaching focused on general tactical principles be carried out until around eight years old (Teoldo, et al., 2021). Thus, the establishment of the opposition in players older than eight only through numerical relations may be limited, and it is necessary to consider other game factors, such as the players' individual characteristics.

Concerning the teams' composition according to players' individual characteristics, three studies included in this systematic review presented three different parameters used for the opposition establishment (Hůlka, et al., 2015; Praça, et al., 2016; Santos, et al., 2023). PTK appears unsuitable since it provokes only a few changes in physical demands (Praça, et al., 2016). Otherwise, creative behaviour could be an excellent variable to provoke changes in collective tactical behaviour and in the creative behaviour itself when used in addition to numerical relation (Santos, et al., 2023). Still related to creativity, a limitation of the instrument used to assess creative behaviour is that it only assessed creativity with the ball (Santos, et al., 2023, 2017). Then, it could be a problem during training sessions using SSG with many players because they will probably spend more time without ball possession when their creative behaviour with the ball has less impact. Lastly, the experts' subjective evaluation could be helpful and be used to alter physical demands (Hůlka, et al., 2015). The problem with this kind of subjective evaluation is that it could not correspond to the actual capabilities of the player (Daga, Veglio, Cherasco, & Agostino, 2023; Dugdale, Sanders, Myers, Williams, & Hunter, 2020), even more so in contexts of homogeneous conditions (Dugdale, et al., 2020).

Therefore, the suggestion for future studies and people involved with the training of soccer is to establish the opposition levels through reliable and validated instruments using parameters that are related to all dimensions of the game (namely: tactical, technical, physical, and psychological), such as the decision-making (Teoldo, Cardoso, & Machado, 2021). Furthermore, these parameters must be in accordance with the age and level of expertise of the players involved. Another suggestion regards the inclusion of psychological variables in the studies since psychological parameters are very relevant to sports performance (Fawver, et al., 2020; Wachsmuth, Feichtinger, Bartley, & Höner, 2024) and could give a broad perspective of the opponents. Finally, concerning the methodological aspects, including sample size justification would allow other researchers to know how possible it is to transfer the results found in that sample to other populations (Lakens, 2022). Furthermore, adding the dropout reporting could also enhance the evidence found and further contribute to the scientific advancement of the area.

This study was the first to scope peer-reviewed literature on: i) the effects of the the opposition on individual and collective behaviours in soccer training, ii) how was the level of the opposition established during training sessions, and iii) how the variables were analysed and what instruments were utilized to measure those effects. However, some limitations, like the data collection up to the 10th April 2023, could have influenced the results regarding the lack of more recent research. Our findings suggest that there are two ways in the literature to establish levels of the opposition: numerical relations and through teams' composition according to players' individual characteristics. Moreover, according to the results discussed in this systematic review, manipulating levels of the opposition through numerical relations and players' characteristics affects tactical, technical, and physical dimensions during soccer training. Manipulating the opposition through numerical relationships can facilitate the exchange of passes and maintenance of ball possession, in the offensive phase, and generate greater commitment in attempts to recover possession of the ball in the defensive phase. Regarding the individual characteristics of the players, the effects of the opposition depend mainly on the variable used in organising the teams. Therefore, it is important to know these effects and how it could be possible to manipulate the opposition levels according to the aims of the training, besides the age and level of expertise of the players.

References

Aquino, R., Carling, C., Palucci Vieira, L.H., Martins, G., Jabor, G., Machado, J., Santiago, P., Garganta, J., & Puggina, E. (2020). Influence of situational variables, team formation, and playing position on match running performance and social network analysis in Brazilian professional soccer players. *Journal of Strength and Conditioning Research*, *34*(3), 808-817. https://doi.org/10.1519/JSC.0000000000002725

Augusto, D., Oliveira, L.A., Aquino, R., Fernandes, I., Bezerra Almeida, M., & Vasconcellos, F. (2022). Within-subject variation of technical performance in elite Brazilian professional soccer players: The environmental stress, match location, and opposition's ranking influences. *International Journal of Performance Analysis in Sport*, *22*(4), 583-593. https://doi.org/10.1080/24748668.2022.2097835

Castelo, J. (1996). *Futebol a organização do jogo: Como entender a organização dinâmica de uma equipe de futebol e a partir desta compreensão como melhorar o rendimento e a direção dos jogadores e da equipa*. [Soccer the organization of the game: How to understand the dynamic organization of a soccer team and from this understanding how to improve the performance and direction of the players and the team]. Lisboa: FMH Edições.

Daga, F.A., Veglio, F., Cherasco, G.M., & Agostino, S. (2023). The influence of subjective perceptions and the efficacy of objective evaluation in soccer school players' classification: A cross-sectional study. *Children*, *10*(5), 767-779. https://doi.org/10.3390/children10050767

Dugdale, J.H., Sanders, D., Myers, T., Williams, A.M., & Hunter, A.M. (2020). A case study comparison of objective and subjective evaluation methods of physical qualities in youth soccer players. *Journal of Sports Sciences*, *38*(11-12), 1304-1312. https://doi.org/10.1080/02640414.2020.1766177

Faber, I.R., Bustin, P.M.J., Oosterveld, F.G.J., Elferink-Gemser, M.T., & Nijhuis-Van der Sanden, M.W.G. (2016). Assessing personal talent determinants in young racquet sport players: A systematic review. *Journal of Sports Sciences*, *34*(5), 395-410. https://doi.org/10.1080/02640414.2015.1061201

Fawver, B., Cowan, R L., DeCouto, B S., Lohse, K R., Podlog, L., & Williams, A M. (2020). Psychological characteristics, sport engagement, and performance in alpine skiers. *Psychology of Sport and Exercise*, *47*, 101616. https://doi.org/10.1016/j.psychsport.2019.101616

Fernandez-Navarro, J., Fradua, L., Zubillaga, A., & McRobert, A.P. (2018). Influence of contextual variables on styles of play in soccer. *International Journal of Performance Analysis in Sport*, *18*(3), 423-436. https://doi.org/10.1080/24748668.2018.1479925

Garganta, J., & Gréhaigne, J.F. (1999). Abordagem sistêmica do jogo de futebol: Moda ou necessidade? [Systemic approach to the game of soccer: Fashion or necessity?] *Movimento*, *5*(10), 40-50. https://doi.org/10.22456/1982-8918.2457

Garganta, J., & Pinto, J. (1994). O ensino do futebol. [The teaching of soccer game.] In A. Graça & J. Oliveira (Eds.), *O ensino dos jogos desportivos [The teaching of sportive games]* (pp. 95-136). Faculdade de Ciências do Desporto e de Educação Física da Universidade do Porto: Rainho & Neves Lda.

Gonçalves, B., Marcelino, R., Torres-Ronda, L., Torrents, C., & Sampaio, J. (2016). Effects of emphasising opposition and cooperation on collective movement behaviour during football small-sided games. *Journal of Sports Sciences*, *34*(14), 1346-1354. https://doi.org/10.1080/02640414.2016.1143111

Greco, P., Campos Aburachid, L., Da Silva, S., & Perez Morales, J. (2014). Validação de conteúdo de ações tático-técnicas do Teste de Conhecimento Tático Processual – Orientação Esportiva. [Content validation of tactical-technical actions in the Tactical Procedural Knowledge Test—Sports Orientation.]. *Motricidade*, *10*(1). https://doi.org/10.6063/motricidade.10(1).2124

Gréhaigne, J.-F., & Godbout, P. (2014). Dynamic systems theory and team sport coaching. *Quest*, *66*(1), 96-116. https://doi.org/10.1080/00336297.2013.814577

Hůlka, K., Weisser, R., Bělka, J., & Háp, P. (2015). The influence of different level of opponents on internal responses and external loads during small-sided games in soccer. *Acta Gymnica*, *45*(3), 113-119. https://doi.org/10.5507/ag.2015.017

Ibáñez, S.J., Pérez-Goye, E., García-Rubio, J., & Courel-Ibáñez, J. (2020). Effects of task constraints on training workload in elite women's soccer. *International Journal of Sports Science and Coaching*, *15*(1), 99-107. https://doi.org/10.1177/1747954119891158

Júlio, L., & Araújo, D. (2005). Abordagem dinâmica da acção táctica no jogo de futebol. [A dynamic approach to tactical action in the game of soccer.] In D. Araújo (Ed.), *O contexto na decisão: A ação tática no desporto [Context in decision-making: Tactical action in sport]* (pp. 159-177). Lisboa: Visão e Contextos Lda.

Lago-Peñas, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences*, *27*(13), 1463-1469. https://doi.org/10.1080/02640410903131681

Lakens, D. (2022). Sample size justification. *Collabra: Psychology, 8*(1), 33267. https://doi.org/10.1525/collabra.33267

Law, M., Stewart, D., Pollock, N., Letts, L., Bosch, J., & Westmorland, M. (1998). *Critical review form: Quantitative studies*. Hamilton: McMaster University.

Nunes, N., Gonçalves, B., Coutinho, D., & Travassos, B. (2020). How numerical unbalance constraints physical and tactical individual demands of ball possession small-sided soccer games. *Frontiers in Psychology*, *11*, 1464. https://doi.org/10.3389/fpsyg.2020.01464

Nunes, N., Gonçalves, B., Roca, A., & Travassos, B. (2021). Effects of numerical unbalance constraints on workload and tactical individual actions during ball possession small-sided soccer games across different age groups. *International Journal of Performance Analysis in Sport*, *21*(3), 396-408. https://doi.org/10.1080/24748668.2021.1903249

Ometto, L., Vasconcellos, F.V., Cunha, F.A., Teoldo, I., Souza, C.R.B., Dutra, M.B., ..., & Davids, K. (2018). How manipulating task constraints in small-sided and conditioned games shapes emergence of individual and collective tactical behaviours in football: A systematic review. *International Journal of Sports Science and Coaching*, *13*(6), 1200-1214. https://doi.org/10.1177/1747954118769183

Page, M., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., Mulrow, C., …, & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *The BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Praça, G., Fagundes, L., Braga, W., Folgado, H., Morales, J., Chagas, M., Andrade, A., & Greco, P. (2016). Influência da alteração do adversário nas respostas táticas e físicas em pequenos jogos no futebol. [Influence of changing the opponent in tactical and physical demands in soccer small-sided games]. *Revista Brasileira de Ciência e Movimento*, *24*(4), 44-54. https://doi.org/10.18511/rbcm.v24i4.6308

Práxedes, A., Moreno, A., Gil-Arias, A., Claver, F., & Del Villar, F. (2018). The effect of small-sided games with different levels of opposition on the tactical behaviour of young footballers with different levels of sport expertise. *PLoS ONE*, *13*(1), e0190157. https://doi.org/10.1371/journal.pone.0190157

Práxedes, A., Pizarro, D., Travassos, B., Dominguez, M., & Moreno, A (2021). Level of opposition constrains offensive performance in consecutive game situations. An analysis according to game principles. *Physical Education and Sport Pedagogy*, *27*(3), 291-303. https://doi.org/10.1080/17408989.2021.1877269

Ric, A., Hristovski, R., Gonçalves, B., Torres, L., Sampaio, J., & Torrents, C. (2016). Timescales for exploratory tactical behaviour in football small-sided games. *Journal of Sports Sciences*, *34*(18), 1723-1730. https://doi.org/10.1080/02640414.2015.1136068

Santos, S., Coutinho, D., Gonçalves, B., & Sampaio, J. (2023). How many creatives are enough? Exploring how manipulating the number of creative players in the opposing team impacts footballers' performance during small-sided games. *Human Movement Science*, *87*, 103043. https://doi.org/10.1016/j.humov.2022.103043

Santos, S., Jimeénez, S., Sampaio, J., & Leite, N. (2017). Effects of the Skills4Genius sports-based training program in creative behavior. *PLoS ONE*, *12*(2), e172520. https://doi.org/10.1371/journal.pone.0172520

Sarmento, H, Anguera, M., Pereira, A., & Araújo, D. (2018). Talent identification and development in male football: A systematic review. *Sports Medicine*, *48*(4), 907-931. https://doi.org/10.1007/s40279-017-0851-7

Sarmento, H, Clemente, F., Araújo, D., Davids, K., McRobert, A., & Figueiredo, A. (2018). What performance analysts need to know about research trends in association football (2012–2016): A systematic review. *Sports Medicine*, *48*, 799-836. https://doi.org/10.1007/s40279-017-0836-6

Sarmento, H., Clemente, F., Harper, L.D., Teoldo, I., Owen, A., & Figueiredo, A. (2018). Small sided games in soccer–A systematic review. *International Journal of Performance Analysis in Sport*, *18*(5), 693-749. https://doi.org/10.1080/24748668.2018.1517288

Taylor, J., Mellalieu, S., James, N., & Shearer, D. (2008). The influence of match location, quality of opposition, and match status on technical performance in professional association football. *Journal of Sports Sciences*, *26*(9), 885-895. https://doi.org/10.1080/02640410701836887

Teoldo, I., Cardoso, F., & Machado, G. (2021). Tomada de decisão no futebol: da avaliação à aplicação em campo. [Decision-making in soccer: From assessment to application on the pitch.] In W. Matias & P. Athayde (Eds.), *Nas entrelinhas do futebol: espetáculo, gênero e formação. [Between the lines of soccer: Spectacle, gender and education.]* (pp. 187-205). Editora CRV.

Teoldo, I., Guilherme, J., & Garganta, J. (2021). *Football intelligence: Training and tactics for soccer success*. Routledge.

Teoldo, I., Silva, J., Greco, P., & Mesquita, I. (2009). Princípios táticos do jogo de futebol: conceitos e aplicação. [Core tactical principles of soccer game: From concept to the application.] *Motriz*, *15*(3), 657-668. https://doi.org/10.5016/2488

Torrents, C., Ric, A., Hristovski, R., Torres-Ronda, L., Vicente, E., & Sampaio, J. (2016). Emergence of exploratory, technical and tactical behavior in small-sided soccer games when manipulating the number of teammates and opponents. *PLoS ONE*, *11*(12), e168866. https://doi.org/10.1371/journal.pone.0168866

Torres-Ronda, L., Gonçalves, B., Marcelino, R., Torrents, C., Vicente, E., & Sampaio, J. (2015). Heart rate, time-motion, and body impacts when changing the number of teammates and opponents in soccer small-sided games. *Journal of Strength and Conditioning Research*, *29*(10), 2723-2730. https://doi.org/10.1519/JSC.0000000000000932

Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., & Vanda, C. (2012). Informational constraints shape emergent functional behaviours during performance of interceptive actions in team sports. *Psychology of Sport and Exercise*, *13*(2), 216-223. https://doi.org/10.1016/j.psychsport.2011.11.009

Travassos, B., Vilar, L., Araújo, D., & McGarry, T. (2014). Tactical performance changes with equal vs unequal numbers of players in small-sided football games. *International Journal of Performance Analysis in Sport*, *14*(2), 594-605. https://doi.org/10.1080/24748668.2014.11868745

Wachsmuth, S., Feichtinger, P., Bartley, J., & Höner, O. (2024). Psychological characteristics and future success: A prospective study examining youth soccer players at different stages within the German talent development pathway. *Journal of Applied Sport Psychology*, *36*(2), 276-300. https://doi.org/10.1080/10413200.2023.2224868

Wierike, S.C.M., Van Der Sluis, A., Van Den Akker-Scheek, I., Elferink-Gemser, M.T., & Visscher, C. (2013). Psychosocial factors influencing the recovery of athletes with anterior cruciate ligament injury: A systematic review. *Scandinavian Journal of Medicine and Science in Sports*, *23*(5), 527-540. https://doi.org/10.1111/sms.12010

Yi, Q., Ángel-Gómez, M., Liu, H., & Sampaio, J. (2019). Variation of match statistics and football teams' match performance in the group stage of the EUFA Champions League from 2010 to 2017. *Kinesiology*, *51*(2), 170-181. https://doi.org/ 10.26582/k.51.2.4

Submitted: May 6, 2024
Accepted: October 4, 2024
Published Online First: December 24, 2024

Correspondence to:
Victor Reis Machado
Centre of Research and Studies in Soccer,
Universidade Federal de Viçosa,
Av. PH Rolfs,
SN - University Campus - Centre, Viçosa, Brazil.
Email: victor.machado1@ufv.br

Declaration of competing interest

The authors have no conflicts of interest to declare.

Funding

This study was supported by the Sports incentive law of the Government of Minas Gerais, by the Academy & Soccer Program of the Ministry of Citizenship, through the National Secretariat of Football and Defense of Fans' Rights; the SEESP-MG, FAPEMIG, CNPq, Funarbe, the Dean's Office for Graduate and Research Studies and the Centre of Life and Health Sciences from the leading institution. This study was also financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) – Finance Code 001.

COMPETITIVE ANXIETY AND SELF-EFFICACY IN YOUNG VOLLEYBALL PLAYERS: A SEASON TREND STUDY OF THEIR RECIPROCAL EFFECT ON MATCH OUTCOMES

Francine Caetano de Andrade Nogueira[1], Maurício Gattás Bara Filho[2], Cristiano Diniz da Silva[3], Danilo Reis Coimbra[3], and Lelio Moura Lourenço[4]

[1]Federal University of Rio de Janeiro, School of Physical Education and Sports, Rio de Janeiro, RJ, Brazil
[2]Federal University of Juiz de Fora, School of Physical Education and Sports, Department of Sports, Juiz de Fora, MG, Brazil
[3]Federal University of Juiz de Fora, Life Sciences Institute, Governador Valadares, MG, Brazil
[4]Federal University of Juiz de Fora, School of Psychology, Center for Violence and Social Anxiety Studies, Juiz de Fora, MG, Brazil

Original scientific paper
DOI 10.26582/k.56.2.13

Abstract:

The aim of this study was to evaluate: i) the changes and interrelationships of competitive anxiety (CA) and self-efficacy responses; and ii) the predictive power of these variables and the competitive context in predicting match-by-match performance of a volleyball team in an entire season. The sample consisted of 15 Brazilian high-performance male volleyball players (U-18). The outcomes were somatic CA, cognitive CA, and self-confidence measured with the Competitive Anxiety Questionnaire in Sports (CSAI-2R), and self-efficacy, assessed with the Individual Self-Efficacy Scale for Volleyball. The athletes answered the questionnaires before each match during the season (N=24 matches). The athletes presented higher somatic and cognitive CA and lower self-confidence at the beginning of the competitive phase. Trend-repeated measures analysis showed seasonal variations with a decrease in somatic (~57%) and cognitive (~62%) CA and increase in self-confidence (~40%) and self-efficacy (~16%). Self-efficacy presented a high and positive correlation with self-confidence (rho=0.56, p<.05), but did not correlate with CA. Binary logistic regression revealed that previous matches with an "easy" degree of intensity (i.e., 3-set duration) estimated a 230% increase in the chance of winning the next match compared to previous matches with "moderate intensity" (i.e., 4-set duration). The likelihood of wins in the morning matches was 152% more likely as compared to afternoon matches. Winning odds increased about 3% for every 1-unit increase in precompetitive self-efficacy and decreased 12% for each somatic CA 1-unit increase. It is concluded that the degree of intensity of previous contests (regardless of the match outcome) and match day period seem to interact with self-efficacy. Understanding seasonal variations and the transient competitive context enables better management of athletes' psychological skills.

Key words: *performance, team sports, CSAI-2R, repeated measures analysis*

Introduction

Volleyball is a team sport with intermittent characteristics, in which the main actions of the game are performed at high intensity involving successive jumps, multidirectional movements, and lower limb power associated with explosive strength. Alongside this high physical demand, volleyball features a high degree of complexity and cognitive requirement due to the unpredictability of opponent actions and reactive decision-making process (Andrade, Fernandes, Miranda, Coimbra, & Bara Filho, 2021; Costa, et al., 2017; Fortes, Fiorese, Nascimento-Júnior, Almeida, & Ferreira, 2019; Marcelino, Mesquita, & Sampaio, 2011). In addition to the inherent physical and mental fatigue associated with volleyball, the competitive nature of the sport (including travel, disruption of routines, rival fans, and the pressure of results) and the rapid rate of information transfer with coaches and teammates require players to manage a range of skills. As a result, coping with the physical, perceptual-cognitive, and logistical demands of competitive sport can lead to increased anxiety during training sessions and especially during the major competitions of the season (Andrade, Bevilacqua, Coimbra, Pereira, & Brandt, 2016; Aoki, et al., 2017; Brazo-Sayavera, et al., 2017; Fortes, et al., 2021).

Competitive anxiety (CA) can be defined as a perception of competitive situations as threatening, in which athletes generally respond by feeling apprehension and physiologically aroused (Martens, Vealey, & Burton, 1990). The current consensus is that CA comprises three distinct dimensions: cognitive CA, characterized by elements such as worrisome thoughts, negative self-evaluations, and uncertainties regarding performance; somatic CA, manifested through physical activation, tension, and an elevated heart rate; and self-confidence, denoting the athlete's belief and assurance in their own capacity to perform (Brandão & Amaro 2023; Fernandes, Nunes, Raposo, Fernandes, & Brustad, 2013; Martens, et al., 1990). In a systematic review of 27 studies, Rocha and Osório (2018) found that individual differences in athletes' CA levels could be explained by sociodemographic (i.e., gender and age), sporting profile (i.e., experience, previous performance), and sport context (i.e., type of sport and match intensity).

In this sense, CA and its relation with performance have been widely studied by researchers in the field of sport psychology (Chuang, Huang, & Hung, 2015; Englert & Bertrams, 2012; Fernandes, et al., 2013; Fortes, Lira, de Lima, Almeida, & Ferreira, 2016; Fortes, et al., 2017; Franklin, Smith, & Holmes, 2015). For example, cognitive CA in elite athletes has a weak and inverse correlation with performance, while for the European club level, somatic CA has a stronger and positive correlation with performance (Craft, Magyar, Becker, & Feltz, 2003). One possible explanation is that cognitive CA can predispose athletes toward aversive self-appraisals and disruptions in attention processing, while somatic CA may have a curvilinear relationship with performance. In other words, it can affect performance in the moments before the competition, but dissipate after the beginning of the game (Barrett, Kannis-Dymand, Love, Ramos-Cejudo, & Lovell, 2023).

Given that CA can exhibit a direct correlation with sports performance (Costa, Fernandes, Silva, & Batista, 2019; Craft, et al., 2003; Fortes, et al., 2019) or be associated with other psychological variables (Chun, Lee, Kim, Cho, & Lee, 2022), it becomes imperative to explore additional variables that could be interconnected with or mediating the relationship between CA and performance. For example, Brandão and Amaro (2023) found that cognitive reappraisal, a component of emotion regulation, was significantly associated with self-confidence, whereas extroversion (personality) was significantly associated with somatic CA.

In the context of sport, self-efficacy emerges as an important component linked with athletes' performance (Đurović, Popov, Sokić, Grujić, & Aleksić Veljković, 2021; Moritz, Feltz, Fahrbach, & Mack, 2000; Reverdito, et al., 2023; Sivrikaya, 2019). Self-efficacy can be conceptualized as the individual's belief in his/her ability to perform a specific task successfully that will lead to desired outcomes (Bandura, 1997). Self-efficacy has been described as one of the most influential psychological variable for sport performance (Moritz, et al., 2000; Mouloud & El-Kadder, 2016), with moderate to large correlations and reciprocal effects (Moritz, et al., 2000). This means self-efficacy can arise from a previous positive outcome, and simultaneously this self-efficacy appears to promote better subsequent performance (Lochbaum, et al., 2022). Additionally, as proposed by Bandura in the Social Cognitive Theory (Bandura, 1997), self-efficacy stems from four sources: mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states.

One of the ways in which athletes' self-efficacy can influence their performance is through the potential role to regulate positive emotional states, such as pleasure and satisfaction, and negative emotional states, such as boredom and CA (Feltz, Short, & Sullivan, 2008). CA can adversely affect self-efficacy, and the possibility of diminished self-efficacy may in turn exert a negative impact on sports achievement. Conversely, how this relationship occurs is still poorly investigated. Chun et al. (2022) showed that cognitive and somatic CA had a negative correlation with perceived performance, while self-confidence showed a positive correlation with perceived performance. On the other hand, self-confidence can positively influence the relationship between CA and performance. Additionally, higher levels of self-efficacy can help athletes become less susceptible to the negative effects of CA during matches, thus improving performance (Besharat & Pourbohlool, 2011).

Valiante and Morris (2013) investigated the importance of previous performances in the sources of self-efficacy in golfers. The golfers were able to maintain high levels of self-efficacy for a long time by recalling successful events. According to Sivrikaya (2019), the maintenance of these self-efficacy levels suggests that previous experiences can benefit athletes' performance, and this benefit can remain for a long time. Sivrikaya (2019) found that self-efficacy is necessary for the success of athletes, because the belief that a person has about his/her power to affect the situation influences the way that person faces challenges competently, making better choices. In this regard, these connections should be strengthened when working with young athletes. Furthermore, young athletes, who have less deliberate practice time compared to professionals, may be vulnerable during match days, which potentially impacts their psychological well-being, tactical comprehension of the game, and perceptual-cognitive skills, thus adversely affecting performance (Rice, et al., 2016; Rocha & Osório, 2018). Interestingly, competitive anxiety (CA) and self-confidence have not yet been evaluated as potential sources of self-efficacy that can influence athletes' performance. Understanding how these psychological demands and contextual variables from previous matches influence performance could assist youth volleyball players in managing their emotions, developing cognitive routines, and filtering out irrelevant stimuli to maximize their chances of winning.

In addition, the seasonal variation effect of athletes' CA may coexist with peak training loads, poor recovery, and proximity to major competition. Thus, understanding transient and psychological performance-dependent behavior throughout the season emerges as another skill demanded by coaches.

Therefore, the present study aimed to evaluate the seasonal change and the interrelationship between CA, self-efficacy, and the predictive explanatory power of these psychological variables and the competitive context in predicting the next game performance throughout the season in a young volleyball team. Considering the contextual variables, we hypothesized that: i) self-confidence response will correlate with self-efficacy; ii) competitive anxiety (somatic and cognitive), self-confidence, and self-efficacy are predictors of winning matches.

Methods

Participants

A total of 15 male athletes from the Under-18 category of a professional elite volleyball team in Brazil participated in this study (mean age: 16.29±1.72 years; range 15 to 17 years; weight: 71.8±5.4 kg; height: 182.3±3.7 cm; %body fat: 11.8±5.6%). The volleyball team was selected by convenience. The team participated in state- and national-level competitions (i.e., the Superliga, the most important volleyball championship in Brazil); and one athlete of this sample represented the Brazilian team in international championships. At the time it was surveyed, the sampled team was among the top three in the state-level competitions. The inclusion criteria for this study were the following: being an athlete on the team; training routinely; and participating in at least 10 matches during the competitive season. The exclusion criterion was injury during the season and missing more than 15% of the training sessions. All athletes and their legal guardians signed an informed consent term attesting to their voluntary participation. The study was approved by the Ethics Committee on Research in Human Beings, protocol number (663 188/2014), in accordance with the Declaration of Helsinki.

The young athletes trained five days a week, from Monday to Friday, 2-3 hours a day, in the afternoon (Table 1). In training sessions, they performed physical, technical, and tactical exercises with and without the ball. In addition, the athletes had strength training three times a week for one hour, and functional, core, and mobility training twice a week. The complete season schedule is shown in Figure 1.

Experimental approach

We followed an observational study design with the study's deductive logic launched *a posteriori*. Thus, the technical staff and participants received no feedback from the research team. On the day of the presentation of the team for the season, after consent from the technical committee, the researchers explained the study objectives, promoted familiarization with the instruments, and any doubts were clarified.

The athletes completed the Individual Self-Efficacy Scale for Volleyball (Carmo, 2006) and the Competitive State Anxiety Inventory – 2, short version (CSAI-2R) developed by Martens et al. (1990) and translated, adapted, and validated for Brazilian athletes by Fernandes, Vasconcelos-Raposo, and Fernandes (2012) before all matches

Table 1. Overview of the scheduled activities (e.g., strength training, technical and tactical training, and competitions) during a typical training week for the team

Days/hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
2 to 3 p.m.	ST	FCM	ST	FCM	ST	OFF	OFF
3 to 5 p.m.	Setting and receiving the serve/ attacking, digging and blocking/ serving; TT	Setting and receiving the serve/ attacking, digging and blocking/ serving; Tactical	Setting and receiving the serve/ attacking, digging and blocking/ serving TT	Setting and receiving the serve/ attacking, digging and blocking/ serving; Tactical	Setting and receiving the serve/ attacking, digging and blocking/ serving; TT		

Note: ST: strength training; FCM: functional, core, and mobility training; TT: technical and tactical training.

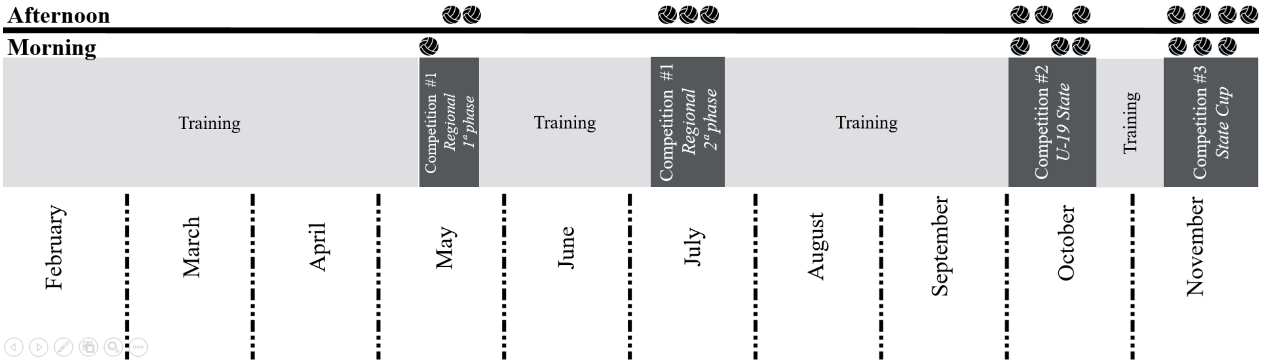


Figure 1. Season schedule.

played by the team throughout the season. The athletes familiarized themselves with the questionnaire before commencing data collection. Athletes were approached individually about an hour before the start of each match. It took an average of 10 minutes to complete the questionnaires. The researchers remained at the data collection site throughout the procedure. All athletes were familiarized with the instruments.

The team was monitored in all championships during the training season. The team participated in three championships, with 24 matches during the entire competitive season. The total duration of the sampled season was 10 months (February to November). The first games of each championship were excluded for the trend-repeated measures analysis of the effect of previous match context outcome. Thus, 19 matches were considered for this analytical approach. Our purpose was to explore the change throughout the season in the psychological skills variables, their intercorrelation and predictive power in the competitive context for performance in the next match by data modelling.

Procedures

Monitoring self-efficacy

The Individual Self-Efficacy Scale for Volleyball (Carmo, 2006) is composed of eight items that question the athlete about the degree of confidence they have in their ability to perform important skills in the game. Each answer contains a Likert scale of 11 points, ranging from 0 = "I cannot do it at all" to 10 = "of course I can do it". Carmo (2006) did the process of adaptation and validation for Portuguese language and the scale presented an internal consistency of α= 0.80 for pass hitters, middle blockers, outside hitters, and setters, demonstrating applicability for a Brazilian sample.

Monitoring competitive anxiety

We used the CSAI-2R translated and validated into Portuguese by Fernandes et al. (2012) to measure the somatic and cognitive CA and self-confidence levels. This instrument consists of 17 Likert-type questions, in which the subject chooses: 1 = *nothing*, 2 = *something*, 3 = *moderate*, and 4 = *very*, according to the question. A score of three subscales (cognitive CA, questions 2, 5, 8, 11, and 14; somatic CA, questions 1, 4, 6, 9, 12, 15, and 17, and self-confidence, questions 3, 7, 10, 13, and 16) is obtained from the sum of responses, with scores ranging from 5 to 20 for the cognitive CA and self-confidence levels, and 7 to 28 for the somatic CA level.

Competitive context variables

Three competitive situational exploratory variables relating to the previous match (degree of intensity and its outcome) and match day period (morning and afternoon) were considered. The assignment of degree of intensity of the previous match followed the classification: "easy", matches with three sets (3x0); "moderate", matches with four sets (3x1); and "difficult", matches with five sets (3x2). The attribution of the match intensity was considered in previous studies (Arruda, Aoki, Freitas, Coutts, & Moreira, 2013; Debien, et al., 2018; Kelly & Coutts, 2007; Lima, Silva, Afonso, Castro, & Clemente, 2020). This variable was categorized independently of the match result. Thus, the previous match outcomes were categorized as lost or won. The same binary response was assigned to the next match that was used as the dependent variable. The final analysis included 296 individual data items.

Statistical analysis

Data are presented as mean ± standard deviation, median, interquartile range, counts, and percentage (%). The smallest worthwhile change (SWC) was characterized as 0.5 x within-player SD of magnitude of deviation from trend line responses during the season. Effect magnitudes (± 90% CI) were classified according to standard criteria: trivial = 0.0–0.2; small = 0.2–0.6; moderate = 0.6–1.2; large = 1.2–2.0; very large = 2.0–4.0; and extremely large > 4.0 (Hopkins, Marshall, Batterham, & Hanin, 2009). Chances of change over time from deviation from season trend line were assessed qualitatively as follows: <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely (Hopkins, et al., 2009). Changes of less than the SWC were considered trivial, and where the 90% CI overlapped positive and the negative thresholds simultaneously, the effect was deemed unclear. Spearman's test (rho) using p-value adjustment by the Holm (1979) method was used to verify the correlation between the variables. The rho's confidence intervals were calculated by bootstrap (1000 within-individuals resamples; 95% CI_{boot}) using the normal approximation criterion. The rho coefficient was evaluated as proposed by Hopkins et al. (2009): <0.10 (trivial), 0.10 to 0.30 (low), 0.31 to 0.50 (moderate), 0.51 to 0.70 (high), 0.71 to 0.90 (very high), 0.91 to 0.99 (almost perfect), and 1 (perfect). A binary logistic regression was fitted with match outcome win ("yes"/"no") as the dependent variable to quantify the effects of exploratory precompetitive and competitive context variables, with self-efficacy, CA (cognitive, somatic, and self-confidence), previous match outcome, match day period and intensity level as covariates in our regressions. The model simplification method adopted was the stepwise-selected lowest Akaike information criterion (AIC) (Venables & Ripley, 2002). Each individual predictions effect size (ES) was obtained by Cohen's odds ratio and interpretation was according to the values |OR| <1.44, very small; |OR| = 1.44 < 2.48, small; |OR| = 2.48 ≤ 4.27, medium; and |OR| > 4.27, large (Cohen, 1988). Statistical significance was set as p<.05. All data analyses were conducted using the R statistical programming language (version 4.1.0; R Foundation for Statistical Computing, Vienna, Austria).

Results

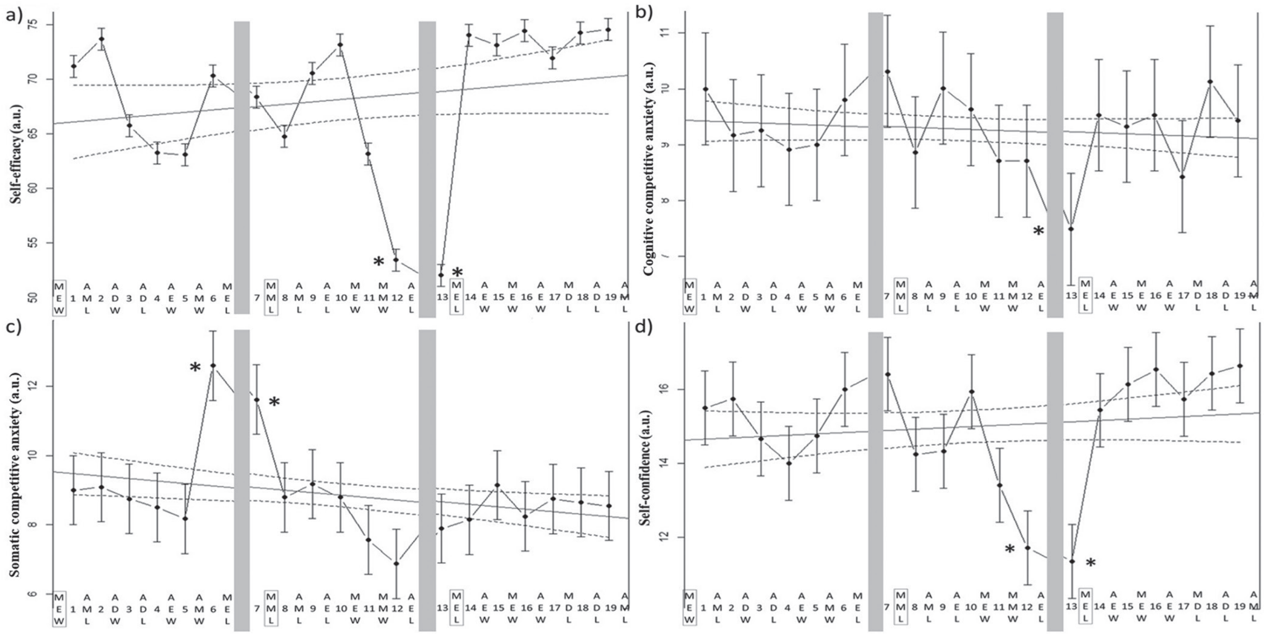
Table 1 reports the descriptive characterization of the sample and competitive context variables under the season period analysis.

Figure 2 presents the repeated measures analysis of psychometric responses and changes from the trend line during the competitive season. As expected, magnitude-based inferences about somatic CA showed a "very likely higher" response at the beginning of the competitive season with an estimated difference of 3.5 a.u. to the decreasing trend line (p<.001). A transient season effect was noted with a significant decrease for self-efficacy (-15.1 a.u.) and self-confidence (-3.4 a.u.) responses between matches 12 and 13 (state-level champ-

Table 2. Descriptive characterization of the psychometric responses and competitive context

Characteristic	**mean ± SD [Median (IQR)]**
Psychometrics	
self-efficacy (a.u)	68 ± 16 [72 (66, 77)]
competitive anxiety	
cognitive (a.u)	9.2 ± 3.6 [9.0 (7.0, 11.0)]
somatic (a.u)	8.8 ± 3.1 [8.0 (7.0, 10.0)]
self-confidence (a.u)	14.9 ± 4.1 [15.0 (14.0, 17.0)]
Competitive context	
score, studied team (unit)	66 ± 14 [64 (55, 75)]
score, opponent (unit)	68 ± 17 [65 (62, 83)]
match length (minutes)	84 ± 17 [81 (72, 88)]
rally (/min)	0.57 ± 0.04 [0.58 (0.54, 0.60)]
period of the day	**n (%)**
afternoon	12 (63%)
morning	7 (37%)
team results	
loss	11 (58%)
win	8 (42%)
intensity degree of previous matches*	
easy	11 (58%)
moderate	5 (26%)
difficult	3 (16%)

Note: SD: standard deviation. IQR, interquartile range. * Includes the first four matches of each championship in the season, which was only used for the purpose of exploratory predictive variables. All other reports consider the 19 analyzed matches.



Note. In the panel: a) self-efficacy; b) cognitive competitive anxiety; c) somatic competitive anxiety; d) self-confidence. a.u. = arbitrary unit. On the x-axis, the numeric value represents the season sequence of the matches considered in analysis (n=19); the top, middle and bottom categorical value represents the match period (M= morning; A= afternoon), degree of intensity of previous matches (E= easy; M= moderate; D = difficult) and match outcome (L = lost game; W = won game), respectively. Categorical values within rectangular frames represent those matches that start a new competition and were used only for predictive analyses. Gray columns represent the time between competitions. * Represents data points for analyzed matches with qualitative inference (all cases with very likely higher/very likely lower; p<.001) for increased/decreased response from magnitude of deviation from trend line over the competitive season. Qualitative inference represents the likelihood that the true value will have the observed magnitude according to Hopkins (2009).

Figure 2. Trend line and magnitude-based inferences for psychometric responses over the competitive volleyball season.

Table 3. Regression coefficients with the result of the match as reference

	Wins (=yes)			
Predictors	*Odds ratios*	*CI*	*p*	*Effect size*
(Intercept)	0.12	0.02 – 0.50	<0.001	
previous match: *difficult*	2.44	0.92 – 6.52	0.071	*small*
previous match: *easy*	3.30	1.54 – 7.43	0.003	*medium*
match period: *morning*	2.52	1.27 – 5.06	0.009	*medium*
self-efficacy	1.03	1.07 – 2.19	0.024	*very small*
competitive anxiety: somatic	0.88	0.47 – 0.97	0.038	*very small*
AIC		273.603		
log-Likelihood		-130.802		

Note: The reference level of the previous match's difficulty degree and match period. Related factors are "moderate" and "afternoon", respectively. Effect size (ES) was obtained by Cohen's odds ratio rules and interpretation was according to the values |OR| <1.44, very small; |OR| = 1.44 < 2.48, small; |OR| = 2.48 ≤ 4.27, medium; and |OR| > 4.27, large (Cohen, 1988).

ionship matches) with a "very likely lower" magnitude (p<.001). At the same time there were cognitive CA responses outside the trend line with "very likely higher" magnitudes (-1.7 a.u.; p<.001). Prior to this transient behavior of the aforementioned divergent psychological responses, confrontations with magnitudes rated as "difficult" and an irregularity in performance (i.e., wins and losses) can be observed.

When performing the Spearman test, it was found that self-efficacy presented a high and positive correlation with self-confidence (rho= 0.56; p<.001, 95% CI_{boot} [0.45, 0.66]) and non-significant correlation with cognitive CA (rho= 0.01; p>.05, 95% CI_{boot} [-0.14, 0.15]) and somatic CA (rho= 0.05; p>.05, 95% CI_{boot} [-0.08, 0.19]). Cognitive CA was moderately correlated to somatic CA, rho= 0.36; p<.001, 95% CI_{boot} [0.24, 0.48] and low and negatively correlated with self-confidence (rho= -0.24; p<.01, 95% CI_{boot} [-0.39, -0.09]). Somatic CA and self-confidence were non-significant (rho= 0.06; p>.05, 95% CI_{boot} [-0.09, 0.21]). Age presented a low and negative correlation with cognitive CA (rho= -0.29; p<.001, 95% CI_{boot} [-0.41, -0.18]) and non-significant correlation with the two other CA constructs (somatic CA, rho= -0.13; p>.05, 95% CI_{boot} [-0.26, 0.01]; self-confidence (rho= 0.01; p>.05, 95% CI_{boot} [-0.14, 0.13]). Age presented a non-significant correlation with self-efficacy (rho= -0.08; p>.05, 95% CI_{boot} [-0.21, 0.04]).

In the binary logistic regression, the covariables "previous match outcome", cognitive CA and self-confidence were removed in the final model fitted for the next match outcome prediction. The final model correctly classified 70% of the cases. After adjusting for all predictors, the odds ratio for match period indicated that the likelihood of wins in the morning was 152% more likely as compared to the afternoon. The "easy" degree of intensity in previous matches showed that the odds of winning in the upcoming game was 230% more likely as compared to moderate intensity. The odds of winning increase by about 3% for every 1-unit increase of self-efficacy. Moreover, the odds of winning decreased 12% for every 1-unit increase of precompetitive somatic CA. Regression coefficients are presented in Table 2. The qualitative interpretation of these odds ratios indicated an effect size of "very small" to "medium" magnitude.

Discussion and conclusion

The present study aimed to evaluate the seasonal change and the interrelationship between competitive anxiety, self-efficacy, and the competitive context to predict the next game performance throughout an entire competitive season in a young volleyball team.

The first hypothesis was confirmed, as self-efficacy presented a high and positive correlation with self-confidence. The repeated measures data analysis, with evidence-based magnitude, shows that the athletes presented higher somatic and cognitive CA values at the beginning of the season and lower self-confidence values in the same period. According to the season trend lines, there was a decrease in somatic and cognitive CA levels and an increase in self-confidence and self-efficacy levels with transient response related to the match outcome. The second hypothesis was partially confirmed. An increase in self-efficacy and decrease in somatic CA were very small predictors of winning matches. Furthermore, the morning period of the matches increased the team's probability of winning (152%) and the other variables were constant.

It was possible to observe that the lowest mean of self-efficacy was in the first half matches of the season, until match number 13. However, throughout the season, "easy matches" (with three sets) increased the team's chances of winning by 230%, and there was a 3% increase in winning chances for every 1 point scored on the self-efficacy scale. Aligned with this, self-efficacy levels started to rise after the 13^{th} game of the season (as shown in Figure 1), and even after losing some matches, these levels did not decrease. Moritz et al. (2000) summarized the reciprocal relationship between self-efficacy and performance. Changes in perceptions of self-efficacy result from cognitive information processing about past successes, which leads to increased self-efficacy through the acquisition of skills and the comparison of results (Azzi, Bandura, & Polydoro, 2008). In other words, success breeds success (Zhao & Zhang, 2023). Sivrikaya (2019) found that maintenance of these self-efficacy levels suggests that previous experiences can benefit athletes' performance, and this benefit can remain for a long time. The results indicate that athletes can potentially raise and sustain their self-efficacy levels throughout the season. Data analysis shows that the results of the matches and how the victory occurred (e.g., easy, moderate, or difficult) were determinants for the increase in these self-efficacy levels.

Athletes with high self-confidence tend to report low cognitive and somatic CA levels (Fernandes, Vasconcelos-Raposo, & Fernandes, 2014; Marín-González, Portela-Pino, Fuentes-García, & Martínez-Patiño, 2022). A low and negative correlation between cognitive CA and self-confidence was confirmed in the current study. In addition, we found a high and positive correlation between self-confidence and self-efficacy. The high self-confidence and self-efficacy and the low CA levels presented reinforce an athlete's perceived ability to deal with stress and CA before the game, helping the athlete to perform their sporting tasks with more success and perform better during the game (Besharat & Pourbohlool, 2011). Craft et al. (2003) showed that self-confidence before the match was associated with low CA and correlated with better performance during the match. Competition results in increased CA levels in athletes; however, they provide positive effects on performance when associated with high self-confidence and self-efficacy levels (Souza, Rech, Sarabia, Añez, & Reis, 2013).

The main result of the present study was the high and positive correlation between self-efficacy and self-confidence. Additionally, the increase in self-efficacy level and decrease in somatic CA levels are predictors of winning matches for these athletes. This makes sense, since CA can reflect the athlete's perception of the importance of competition for themselves or for the team and the degree of concern about the game (Souza, et al., 2013). Somatic CA dissipates during the match due to positive performance responses, favoring self-confidence and influencing self-efficacy.

In a similar approach, Besharat and Pourbohlool (2011) performed a regression analysis for the moderating effect of sport self-efficacy between CA and sport performance. The authors found that only cognitive CA in the equation (step 1) determined a significant negative prediction for sport performance (β=–0.328; R^2= 10%). However, when self-efficacy was entered into the equation (step 2), the authors found a significant moderating effect (R^2= 0.56) on sport performance, as self-efficacy completely changed the significant relations between cognitive CA and sport performance. These results indicate that increasing sport self-efficacy levels decreases the negative association of cognitive CA with sport performance. The authors argue that one reason for these results is that sport self-efficacy can help athletes to be less affected by CA during the match, and therefore perform better (Besharat & Pourbohlool, 2011).

Previous studies have suggested that sociodemographic variables (gender, age, and nationality), athletes' profile (experience, competition level, previous performance, ability to deal with feelings of apprehension), and sport context (type of sport, modality, opponent's level) can influence CA (Guillén & Sánchez, 2009; Parry, Chinnasamy, Papadopoulou, Noakes, & Micklewright, 2011; Ramis, Torregrosa, & Cruz, 2013). Higher levels of CA were observed in athletes who presented worse previous performance, competition in away matches and versus higher opponent's level, influencing performance. However, evidence has not been found to date about diurnal variations in CA and their influence on outcomes achieved (win or lose). Thus, the variables were compared in relation to the turns in which the match took place to verify whether the match period could also influence the match result of young athletes.

For these athletes, the morning period increased the team's probability of winning (152%). The effects of time of day on aerobic performances are conflicting, while it seems that peak values of anaerobic performance are presented in the afternoon-evening (Chtourou & Souissi, 2012). However, regular training at a particular time of day influences diurnal variations.

Practical application

First, in terms of practical application, it is recommended to align the training time with the competition time, aiming to adapt performance to that specific period of the day. Moreover, implementing a pre-performance routine before the match can help regulate the activation level. Second, Reverdito et al. (2023) discovered a positive relationship between increased self-efficacy and higher levels of perceived sport satisfaction. This sense of satisfaction can in turn directly affect decisions regarding continued engagement in sport activities, which is a primary objective among young athletes.

This study has some limitations. The main limitation involves analyzing the team as a unit. Individualized specialization is possible at this level of performance, and the analysis could relate to specific player positions. However, the small sample size made this analysis difficult. Despite this, using bootstrap methods enhanced the reliability of the findings. Second, self-efficacy was assessed using a validated volleyball-specific scale, and performance was evaluated based on match outcomes (win or loss). Future studies should investigate the agreement between the self-efficacy scale and specific tasks performed in volleyball games. Finally, competitive anxiety (CA) in this age group may arise from life context, including school and family, rather than solely from one's own skills or task-related perceptions. Investigating the origins and respective contributions to CA is recommended.

Based on the data analysis, we can conclude that self-efficacy highly correlates with self-confidence (r=0.56) during the entire season, and the context of previous matches has a great influence on the result (win or lose) of the following match. The "easy" intensity level in the previous match shows that the chances of winning greatly increased (230%) in the next matches compared to the previous match with moderate intensity. Likewise, the chance of winning a match in the morning was 152% higher than in the afternoon. Furthermore, the increase in self-efficacy level and decrease in somatic CA levels are predictors of winning matches. These results are very important, as they allow technical staff to know how to enhance the psychological well-being of young volleyball athletes when they work in this context. When carrying out a repeated measures analysis, understanding which situations increase the chances of winning, such as games in the morning, and the level of influence of a previous game on the team's emotional states, is extremely important to continue optimizing the team's performance.

In an applied approach, the results of the present study reinforce the importance of regular participation of young volleyball athletes in championships to develop self-efficacy and self-confidence. An important result is the ecological validity of this research. Data were assessed with repeated measures analysis in a real context of competitions of an Under-19 category of a professional elite volleyball team in all matches of the season. In this sense, coaches, sport psychologists, and athletes should view an adequate level of self-efficacy and somatic CA as a possible facilitating factor, and this could consequently increase athletes' performance.

References

Andrade, A., Bevilacqua, G.G., Coimbra, D.R., Pereira, F.S., & Brandt, R. (2016). Sleep quality, mood and performance: A study of elite Brazilian volleyball athletes. *Journal of Sports Science and Medicine*, *15*(4), 601-605.

Andrade, D.M., Fernandes, G., Miranda, R., Reis Coimbra, D., & Bara Filho, M.G. (2021). Training load and recovery in volleyball during a competitive season. *Journal of Strength and Conditioning Research*, *35*(4), 1082-1088. https://doi.org/10.1519/JSC.0000000000002837

Aoki, M.S., Arruda, A.F., Freitas, C.G., Miloski, B., Marcelino, P.R., Drago, G., …, & Moreira, A. (2017). Monitoring training loads, mood states, and jump performance over two periodized training mesocycles in elite young volleyball players. *International Journal of Sports Science and Coaching*, *12*(1), 130-137. https://doi.org/10.1177/1747954116684394

Arruda, A.F.S., Aoki, M.S., Freitas, C.G., Coutts, A., & Moreira, A. (2013). Planejamento e monitoramento da carga de treinamento durante o período competitivo no basquetebol. [Planning and monitoring training loads during an in-season basketball period.] *Revista Andaluza de Medicina del Deporte, 6*(2), 85-89. https://doi.org/10.1016/s1888-7546(13)70040-6

Azzi, R.G., Bandura, A., & Polydoro, S.A. (2008). *Teoria social cognitiva.* [Social cognitive theory.] São Paulo: Artmed.

Bandura, A. (1997). *Self-efficacy—The exercise of control*. Worth Publishers.

Barrett, E., Kannis-Dymand, L., Love, S., Ramos-Cejudo, J., & Lovell, G.P. (2023). Sports specific metacognitions and competitive state anxiety in athletes: A comparison between different sporting types. *Applied Cognitive Psychology*, *37*(1), 200-211. https://doi.org/10.1002/acp.4040

Besharat, M.A., & Pourbohlool, S. (2011). Moderating effects of self-confidence and sport self-efficacy on the relationship between competitive anxiety and sport performance. *Psychology*, *2*(7), 760-765. https://doi.org/10.4236/psych.2011.27116

Brandão, T., & Amaro, R. (2023). Competitive anxiety in athletes: Emotion regulation and personality matter. *Kinesiology*, *55*(1), 108-119. https://doi.org/10.26582/k.55.1.12

Brazo-Sayavera, J., Nikolaidis, P., Camacho-Cardenosa, A., Camacho-Cardenosa, M., Timón, R., & Olivares, P. (2017). Acute effects of block jumps in female volleyball players: The role of performance level. *Sports*, *5*(2), 30. https://doi.org/10.3390/sports5020030

Carmo, A. (2006). *Adaptação e validação de uma escala de auto eficácia para o voleibol.* [Adaptation and validation of a self-efficacy scale for volleyball.] (Doctoral dissertation, Universidade Metodista de Piracicaba, Piracicaba).

Chtourou, H., & Souissi, N. (2012). The effect of training at a specific time of day: A review. *Journal of Strength and Conditioning Research*, *26*(7), 1984-2005. https://doi.org/10.1519/JSC.0b013e31825770a7

Chuang, L.-Y., Huang, C.-J., & Hung, T.-M. (2015). Competitive trait anxiety and patterns of attentional bias in archers. *International Journal of Sport Psychology*, *46*(4), 337-347.

Chun, D.-R., Lee, M.-Y., Kim, S.-W., Cho, E.-Y., & Lee, B.-H. (2022). The mediated effect of sports confidence on competitive state anxiety and perceived performance of basketball game. *International Journal of Environmental Research and Public Health*, *20*(1), 334. https://doi.org/10.3390/ijerph20010334

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). New York, NY: Routledge.

Costa, G.D.C.T., Maia, M.P., Rocha, A.C.R., Martins, L.R., Gemente, F.R.F., Campos, M.H., ... & Freire, A.B. (2017). Análise da associação do efeito da recepção com os procedimentos de jogo no voleibol de alto nível brasileiro: o caso da equipe campeã da Superliga Feminina. [Association between effect of reception and game procedures in high-level Brazilian volleyball: The case of the women's "Superliga" champion team.] *Revista Brasileira de Cineantropometria e Desempenho Humano*, *19*(6), 663-675. http://dx.doi.org/10.5007/1980-0037.2017v19n6p663

Costa, Y., Fernandes, M., Silva, E., & Batista, G. (2019). Desempenho técnico-tático e ansiedade competitiva no voleibol de praia com jovens atletas: Efeito no resultado do jogo. [*Technical-tactical performance and competitive anxiety in beach volleyball with young athletes: Effect on the game outcome.*] *RBPFEX-Revista Brasileira de Prescrição e Fisiologia do Exercício*, *13*(85), 876-885.

Craft, L.L., Magyar, T.M., Becker, B.J., & Feltz, D.L. (2003). The relationship between the Competitive State Anxiety Inventory-2 and sport performance: A meta-analysis. *Journal of Sport and Exercise Psychology*, *25*(1), 44-65. https://doi.org/10.1123/jsep.25.1.44

Debien, P.B., Mancini, M., Coimbra, D.R., De Freitas, D.G.S., Miranda, R., & Bara Filho, M.G. (2018). Monitoring training load, recovery, and performance of Brazilian professional volleyball players during a season. *International Journal of Sports Physiology and Performance*, *13*(9), 1182-1189. https://doi.org/10.1123/ijspp.2017-0504

Đurović, D., Popov, S., Sokić, J., Grujić, S., & Aleksić Veljković, A. Z. (2021). Rethinking the role of anxiety and self-efficacy in collective sports achievements. *Primenjena psihologija*, *14*(1), 103-115. https://doi.org/10.19090/pp.2021.1.103-115

Englert, C., & Bertrams, A. (2012). Anxiety, ego depletion, and sports performance. *Journal of Sport and Exercise Psychology*, *34*(5), 580-599. https://doi.org/10.1123/jsep.34.5.580

Feltz, D.L., Short, S.E., & Sullivan, P.J. (2008). *Self-efficacy in sport.* Champaign, IL: Human Kinetics.

Fernandes, M.G., Nunes, S.A. N., Raposo, J.V., & Fernandes, H.M. (2014). Efeitos da experiência nas dimensões de intensidade, direção e frequência da ansiedade e autoconfiança competitiva: Um estudo em atletas de desportos individuais e coletivos. [Effects of experience on the intensity, direction and frequency dimensions of competitive anxiety and self-confidence: A study in individual and team sports athletes.] *Motricidade*, *10*(2), 81-89. http://dx.doi.org/10.6063/motricidade.10(2).2930

Fernandes, M.G., Nunes, S.A., Raposo, J.V., Fernandes, H.M., & Brustad, R. (2013). The CSAI-2: An examination of the instrument's factorial validity and reliability of the intensity, direction and frequency dimensions with Brazilian athletes. *Journal of Applied Sport Psychology*, *25*(4), 377-391. https://doi.org/10.1080/10413200.2012.744780

Fernandes, M.G., Vasconcelos-Raposo, J., & Fernandes, H.M. (2012). Propriedades psicométricas do CSAI-2 em atletas brasileiros. [Psychometric properties of the CSAI-2 in Brazilian athletes.] *Psicologia: Reflexao e Critica*, *25*(4), 679-687. https://doi.org/10.1590/S0102-79722012000400007

Fortes, L.D.S., Fiorese, L., Andrade Nascimento-Júnior, J.R., Almeida, S.S., & Ferreira, M.E.C. (2019). Efeito da Ansiedade Competitiva sobre a Tomada de Decisão em Jovens Atletas de Voleibol. [Effect of Competitive Anxiety on Decision Making in Young Volleyball Athletes.] *Psicologia: Teoria e Pesquisa*, *35*, e3538. https://doi.org/10.1590/0102.3772e3538

Fortes, L. de S., Lira, H.A.A. da S., de Lima, R.C.R., Almeida, S.S., & Ferreira, M.E.C. (2016). Mental training generates positive effect on competitive anxiety of young swimmers? *Revista Brasileira de Cineantropometria e Desempenho Humano*, *18*(3), 353-361. https://doi.org/10.5007/1980-0037.2016v18n3p353

Fortes, L.S., da Costa, B.D.V., Paes, P.P., do Nascimento Júnior, J.R.A., Fiorese, L., & Ferreira, M.E.C. (2017). Influence of competitive-anxiety on heart rate variability in swimmers. *Journal of Sports Science and Medicine*, *16*(4), 498-504.

Fortes, L.S., Fonseca, F.S., Nakamura, F.Y., Barbosa, B.T., Gantois, P., De Lima-Júnior, D., & Ferreira, M.E.C. (2021). Effects of mental fatigue induced by social media use on volleyball decision-making, endurance, and countermovement jump performance. *Perceptual and Motor Skills*, *128*(6), 2745-2766. https://doi.org/10.1177/00315125211040596

Franklin, Z.C., Smith, N.C., & Holmes, P.S. (2015). Anxiety symptom interpretation and performance expectations in high-anxious, low-anxious, defensive high-anxious and repressor individuals. *Personality and Individual Differences*, *77*, 27-32. https://doi.org/10.1016/j.paid.2014.12.040

Guillén, F., & Sánchez, R. (2009). Competitive anxiety in expert female athletes: Sources and intensity of anxiety in national team and first division Spanish basketball players. *Perceptual and Motor Skills*, *109*(2), 407-419. https://doi.org/10.2466/pms.109.2.407-419

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65-70.

Hopkins, W.G., Marshall, S.W., Batterham, A.M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3-12. https://doi.org/10.1249/MSS.0b013e31818cb278

Kelly, V.G., & Coutts, A.J. (2007). Planning and monitoring training loads during the competition phase in team sports. *Strength and Conditioning Journal*, *29*(4), 32-37.

Lima, R.F., Silva, A., Afonso, J., Castro, H., & Clemente, F.M. (2020). External and internal load and their effects on professional volleyball training. *International Journal of Sports Medicine*, *41*(07), 468-474. https://doi.org/10.1055/a-1087-2183

Lochbaum, M., Stoner, E., Hefner, T., Cooper, S., Lane, A.M., & Terry, P.C. (2022). Sport psychology and performance meta-analyses: A systematic review of the literature. *PLoS One*, *17*(2), e0263408. https://doi.org/10.1371/journal.pone.0263408

Marcelino, R., Mesquita, I., & Sampaio, J. (2011). Effects of quality of opposition and match status on technical and tactical performances in elite volleyball. *Journal of Sports Sciences*, *29*(7), 733-741. https://doi.org/10.1080/02640414.2011.552516

Marín-González, F.H., Portela-Pino, I., Fuentes-García, J.P., & Martínez-Patiño, M.J. (2022). Relationship between sports and personal variables and the competitive anxiety of Colombian elite athletes of Olympic and Paralympic sports. *International Journal of Environmental Research and Public Health*, *19*(13), 7791. https://doi.org/10.3390/ijerph19137791

Martens, R., Vealey, R.S., & Burton, D. (1990). *Competitive anxiety in sport.* Champaign, IL: Human Kinetics.

Moritz, S.E., Feltz, D.L., Fahrbach, K.R., & Mack, D.E. (2000). The relation of self-efficacy measures to sport performance: A meta-analytic review. *Research Quarterly for Exercise and Sport*, *71*(3), 280-294. https://doi.org/10.1080/02701367.2000.10608908

Mouloud, K., & El-Kadder, B.A. (2016). Self-efficacy, achievement motivation and anxietyof elite athletes. *IOSR Journal of Sports and Physical Education*, *3*(4), 45-48. https://doi.org/10.9790/6737-03044548

Parry, D., Chinnasamy, C., Papadopoulou, E., Noakes, T., & Micklewright, D. (2011). Cognition and performance: Anxiety, mood and perceived exertion among Ironman triathletes. *British Journal of Sports Medicine*, *45*(14), 1088-1094. https://doi.org/10.1136/bjsm.2010.072637

Ramis, Y., Torregrosa, M., & Cruz, J. (2013). Simon & Martens revisited: Competitive anxiety in youth sports. *Revista de Psicología del Deporte*, *22*(1), 77-83.

Reverdito, R.S., Fonseca, S., Lopes, A., Aires, K., Santos Alves, L., Alves De Lima, L., …, & Gonçalves, C. (2023). Sources of sport satisfaction and perceived self-efficacy among Youth in a competitive environment. *Perceptual and Motor Skills*, *130*(3), 1221-1238. https://doi.org/10.1177/00315125231167460

Rice, S.M., Purcell, R., De Silva, S., Mawren, D., McGorry, P.D., & Parker, A.G. (2016). The mental health of elite athletes: A narrative systematic review. *Sports Medicine*, *46*(9), 1333-1353. https://doi.org/10.1007/s40279-016-0492-2

Rocha, V.V.S., & Osório, F.D.L. (2018). Associations between competitive anxiety, athlete characteristics and sport context: Evidence from a systematic review and meta-analysis. *Archives of Clinical Psychiatry (São Paulo)*, *45*(3), 67-74. https://doi.org/10.1590/0101-60830000000160

Sivrikaya, M.H. (2019). The role of self-efficacy on performance of sports skills of football players. *Journal of Education and Training Studies*, *6*(12a), 75. https://doi.org/10.11114/jets.v6i12a.3952

Souza, C.A.D., Rech, C.R., Sarabia, T.T., Añez, C.R.R., & Reis, R.S. (2013). Autoeficácia e atividade física em adolescentes de Curitiba, Paraná, Brasil. [Self-efficacy and physical activity in adolescents from Curitiba, Paraná, Brazil.] *Cadernos de Saúde Pública*, *29*(10), 2039-2048. https://doi.org/10.1590/0102-311X00127312

Valiante, G., & Morris, D.B. (2013). The sources and maintenance of professional golfers' self-efficacy beliefs. *The Sport Psychologist*, *27*(2), 130-142. https://doi.org/10.1123/tsp.27.2.130

Venables, W., & Ripley, B. (2002). *Modern applied statistics with S-PLUS* (4th ed.). New York, NY: Springer.

Zhao, Y., & Zhang, H. (2023). Does success breed success? An investigation of momentum in elite recurve archery. *Psychology of Sport and Exercise*, *66*, 102397. https://doi.org/10.1016/j.psychsport.2023.102397

Submitted: January 15, 2024
Accepted: August 18, 2024
Published Online First: December 24, 2024

Correspondence to:
Danilo Reis Coimbra, Ph.D.
Federal University of Juiz de Fora
R. São Paulo, 745 - Centro, Gov. Valadares,
35010-180
Minas Gerais, Brazil
Phone: (33) 3301-1000 / (48) 988272266
Email: danilo.coimbra@ufjf.br

GUIDELINES FOR CONTRIBUTORS

FOCUS AND SCOPE

Kinesiology – International Journal of Fundamental and Applied Kinesiology (print ISSN 1331- 1441, online ISSN 1848-638X) publishes twice a year scientific papers and other written material from kinesiology (a scientific discipline which investigates the art and science of human movement; in the meaning and scope close to the idiom “sport sciences”) and other adjacent human sciences focused on sport and exercise, primarily from anthropology (biological and cultural alike), medicine, sociology, psychology, natural sciences and mathematics applied to sport in its broadest sense, history, and others. Contributions of high scientific interest, including also results of theoretical analyses and their practical application in physical education, sport, physical recreation and kinesitherapy, are accepted for publication. The following sections define the scope of the journal: Sport and sports activities, Physical education, Recreation/leisure, Kinesiological anthropology, Training methods, Biology of sport and exercise, Sports medicine and physiology of sport, Biomechanics, History of sport and Book reviews with news.

The journal Kinesiology generally accepts original scientific papers, review articles, but takes into consideration meta-analyses, case studies, brief reports, narrative reviews, commentaries and letters to editors.

PEER REVIEW PROCESS

The editorial policy of the Journal pursues the multi-disciplinary aims and nature of kinesiology. This means that the main goal is to promote high standards of scientific research study and scholarship with regard to various human oriented scientific fields that cover the art and science of human movement, exercise and sport from most variable aspects. The research issues include a paramount variety of human responses (or changes from intracellular level to the level of social phenomena) to exercise and sport training programmes, research in motor learning and training, issues of selection, teaching/ learning and mastering of motor skills, performance analysis (quantitative and qualitative alike) and prediction, performance modification and many others relevant to the scientific study of human movement, sport and exercise.

Submissions to the journal will initially be evaluated by the Editorial Board. The topic of the manuscript must be appropriate for the scope of the journal. Manuscripts considered for publication must contain relevant and up-to-date data on theoretical or experimental research or on practical applications in the field of kinesiology. Accordingly, references should not be older than a decade at the maximum. Exceptions are acceptable in cases of a few really fundamental references or in relation to the nature of the scientific field or branch in question and to the topic of the contribution. Providing quotations and references of relevant literature is crucial for the acceptance of the manuscript. If these criteria are met, the submission will undergo a double-blind review process by at least two acknowledged and independent reviews, with the review process taking up to 24 weeks. If these two reviews contradict each other or present opposite opinions, the Editorial Board will consult the third reviewer or in case of strong disagreement even the fourth or the fifth party. The Editorial Board is not obliged to publish papers in the chronological sequence of their receipt or in the sequence in which they have been accepted for publication. This is not due to favoring certain authors but because of the review process itself: some papers need more corrections and improvements and therefore it takes more time to be published.

OPEN ACCESS POLICY

This journal provides immediate open access to its content on the principle that making research freely available to the public supports a greater global exchange of knowledge.

EDITORIAL POLICY

Editors make publication decisions based on the following: the appropriateness of the manuscript for the scope of the journal, general merit of the manuscript, relevant data, editing issues and format, and adherence to reference guidelines. If necessary, Editorial Board is involved in investigations regarding any legal and ethical issues and communicates with the author(s) in case of: plagiarism complaints, multiple, duplicate, concurrent publication/simultaneous publication, misappropriation of research results, research standards violations, undisclosed conflict of interest, allegations of research errors. If these issues are not to be resolved, the Editorial Board will refuse to publish such manuscripts. When investigating research misconduct, Editorial Board will provide maximum safeguards for informants, who must act in good faith, and for subjects of allegations, who will be given an opportunity to respond to allegations and reasonable access to the data and other evidence supporting the allegations.

Editorial Board also deals with suspected salami publications. The final decision on acceptable similarity is with the Editorial Board and will depend on the amount and relevance of the duplicated data. Before making the decision, Editorial Board will contact the author(s). When there is a minor redundancy, and the author(s) gives a satisfactory and honest explanation then the editor can consider publishing a correction article. Corrections must have proper references and all overlaps with the already published data must be clearly mentioned. If the amount of overlap is considered significant and the author(s) does not give a satisfactory explanation, Editorial Board may publish a statement of redundant publication or even retract the article.

Editorial board communicates with peer reviews and in accordance with them decides on the category of the manuscript.

Editorial board secures fair play and confidentiality.

Editorial Board informs peer reviewers of their decision regarding manuscripts. It also informs reviewers of the comments made by other reviewers of the same manuscript.

Editorial Board makes a list of reviewers based on their promptness, objectivity and working in a timely manner. They contribute to the high quality of the journal and can expect to be thanked for the time they take to review manuscripts.

Conflict of Interest, Research Misconduct, Human rights, Informed Consent

Our editorial policy strongly encourages research integrity, respect of human rights, respect of personal data and generally, we support ethics in both research conduct and scientific communication.

Undeclared financial conflicts may seriously undermine the credibility of the journal, the authors and the science itself. The most obvious conflicts of interest are financial relationships such as: employment, stock ownership, grants, patents. Conflicts can also exist as a result of personal relationships, academic competition, and intellectual passion. All authors are requested to disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence or be perceived to influence, their work.

Research misconduct according to NIH policies and procedures for promoting scientific integrity and to American Psychological Association, among others, is defined as:

- Fabrication (making up data or results)
- Falsification (manipulating research materials, equipment, or processes or changing or omitting data or results such that the research is not accurately represented in the research record).
- Plagiarism (appropriating another person's ideas, processes, results, or words without giving appropriate credit).

Ethics is given the highest priority so all activities in conducting research must comply with ethical principles and relevant national, EU and international legislation, for example. the Charter of Fundamental Rights of the European Union and the European Convention on Human Rights. The most common ethical issue usually include: the protection of children, patients and other vulnerable populations, privacy and data protection. We encourage the publishing of research results of a study in which all research participants have signed informed consent and have been given full information on the possible effects of research intervention.

When reporting research involving human data, authors should indicate whether the procedures followed have been assessed by the responsible review committee (institutional and national), or if no formal ethics committee is available, were in accordance with the Helsinki Declaration as revised in 2013.

Editorial policy relies on guidelines of the Committee on publication Ethics regarding redundant publication, which is also considered scientific misconduct.

AUTHOR GUIDELINES

In preparing manuscripts for publication in Kinesiology, the authors should strictly adhere to the guidelines based on the Publication Manual of the American Psychological Association, 6th ed. The manuscripts that have been submitted in accordance with these instructions, and providing they are of interest to the journal, will enter the reviewing procedure. Any manuscript should not ordinarily exceed 25 pages including the abstract, references, and all tables and illustrations. Discursive treatment of the subject matter is discouraged.

Accompanying document

Authors are obliged to fill in accompanying document that covers authorship, research integrity issues and copyright issues. The document can be found journal website and must be uploaded with the manuscript.

Usage of third-party material

Authors are expected to obtain the necessary written permission to include material owned and held in copyright by a third party, including – but not limited to – any proprietary text, illustration, table, or other material, including data, audio, video, film stills, screenshots, musical notation, and any supplemental material. Reproduction of short extracts of text and some other types of material may be permitted on a *limited basis* given that full attribution is given, and the quotation is reproduced accurately. When content is held in the public domain i.e. is not copyrighted, proper attribution is still required.

Manuscript

The journal Kinesiology generally accepts original scientific papers, review articles, but takes into consideration meta-analyses, case studies, brief reports, narrative reviews, commentaries and letters to editors.

The original scientific paper must be an original contribution to the subject treated and divided into the following sections: Introduction, Methods, Results, Discussion and conclusions. The review article should discuss a topic of current interest and have the latest data in the literature. It should outline knowledge of the subject and analyse various opinions regarding the problem. As a rule, these articles are commissioned, but any initiative from any competent author is welcome.

Please, use font Times New Roman, 12-point font size, double space.

Title page

The title page of the manuscript should contain the following information: a concise, but informative title; the full first and family names of the author(s) (do not include degrees); the last author is introduced by “and”; the affiliation of the authors (affiliated institutions and their locations); the name and address of the corresponding author (must include title, degree and position of the corresponding author, phone and fax numbers – zip code for the country and city, and email address). The title of the article must be short and clear, abbreviations are discouraged. The abstract should be informative and self-explanatory without reference to the text of the manuscript. It should include essential results that support the conclusions of the work. Three to six key words, not used in the title, should also be provided. Authors are advised not to use abbreviations in the abstract. The abstract should contain between 100-250 words.

Text of the paper

The text must comprise of:

Introduction

This describes the present state of knowledge of the subject and the aim of the research.

Methods

This section identifies methodologies, equipment and procedures with sufficient details to allow other researchers to reproduce the results; specifies well-known methods including statistical procedures; mentions and provides a brief description of the published methods which are not yet well known; describes new or modified methods at length; justifies their use and evaluates their limits. Units of measurement, symbols and abbreviations must conform to international standards. Measurements of length, height, weight and volume should be given in metric units (metre, kilogram, litre) or their decimal multiples.

Results

The results should be reported as tables and graphs, possibly processed statistically and concisely presented in the text.

Discussion and conclusions (do NOT separate discussion and conclusions)

The authors are expected here to comment on the results and compare them with literature data. The discussion must be rigorous and correspond to experimental data. Practical implications are welcome.

References

The journal uses the APA reference system **(Publication Manual of the American Psychological Association, 6th ed.)**. The list of references may contain only the authors cited in the text. Authors are obliged to include DOIs in their reference lists, if possible.

Reference citations in text

The study should be documented throughout the text by citing the author(s) and date (within parentheses) of the works used in the research, i.e. "… The recent comparison (Hughes, 2001) showed…", or "… Hughes (2001) compared…".

When there are two authors, always cite both names every time the reference occurs in the text. In the text, the surnames should be joined by "and" (Vuleta, Milanović and Jukić (2004) reported...), whereas within parentheses the sign "&" should be used. The same is valid for three and more authors (up to six). Three, four, or five authors should be cited the first time the reference appears in the text; in subsequent referencing, cite only the family name of the first author followed by "et al." – 1st time (Vuleta, Milanović, & Jukić, 2004); 2nd time: (Vuleta, et al., 2004). Six and more authors should always be cited like: the surname of the first author followed by ", et al.". Be sure when shortening two or more references of the same primary author, to keep enough information to distinguish these citations (by citing as many of the subsequent authors as necessary).

Reference list

Alphabetical order of references in the list should be followed. References should be complete and contain all the authors (up to and six) that have been listed in the title of the original publication. Titles of references written in languages other than English should be additionally translated into the English language and enclosed within square brackets. Full titles of journals are required (not their abbreviations). The author of the article is responsible for the accuracy of data and references

The style of referencing should follow the examples below:

Books

Arnold, P.J. (1979). *Meaning in movement and sport and physical education*. London: Heinemann. Bartoluci, M. (2003). *Ekonomika i menedžment sporta* (2nd ed.). [Economics and management of sport. In Croatian.] Zagreb: Informator, Kineziološki fakultet Sveučilišta u Zagrebu.

Journals

Sallis, J.F., & McKenzie, T.L. (1991). Physical education's role in public health. *Research Quarterly for Exercise and Sport*, *62*(2), 124–137. Trstenjak, D., & Žugić, Z. (1999). Sport as a form of social involvement – the case of tennis. *Kinesiology, 31*(2), 50–61.

Chapters in books

Sparkes, A.C. (1997). Reflections on the socially constructed self. In K. Fox (Ed.), *The physical self: From motivation to well-being* (pp. 83–110). Champaign, IL: Human Kinetics.

Rossi, T., & Cassidy, T. (in press). Teachers' knowledge and knowledgeable teachers in physical education. In C. Hardy & M. Mawer (Eds.), *Learning and teaching in physical education*. London: Falmer Press

Chapters in published books of conference proceedings

Siedentop, D. (1998). New times in (and for) physical education. In R. Feingold, R. Rees, G. Barrette, S. Fiorentino, S. Virgilio & E. Kowalski (Eds.), *AIESEP Proceedings, "Education for Life" World Congress* (pp. 210–212). New York: Adelphi University.

Kasović, M., Medved, V., & Vučetić, V. (2002). Testing of take-off capacities in the lower extremities of top football players. In D. Milanović & F. Prot (Eds.), *Proceedings Book of 3rd International Scientific Conference "Kinesiology – New Perspectives"* (pp. 677–680). Zagreb: Faculty of Kinesiology, University of Zagreb.

Electronic resources (computer software, computer and information services, on-line sites)

U.S. Department of Education. (1997). *Title IX: 25 years of progress* /on-line/. Retrieved April 15, 1999 from: www.ed.gov/pubs/TitleIX/title.html

Yi Xiao, D. (2000). Experiencing the library in a panorama virtual reality environment. *Library Hi Tech*, 18, 2, 177–184. Retrieved July 30, 2001 from: http://isacco.anbar.com/vl=666630/cl=8/nw=1/rpsv/cw/ mcb/07378831/v18n2/s9/p177.html

Nonprinted media (Abstract on CD-ROM)

Meyer, A.S., & Bock, K. (1992). The tip-of-the-tongue phenomenon: Blocking or partial activation? /CDROM/. *Memory & Cognition*, *20,* 715–726. Abstract from: SilverPlatter File: PsycLIT Item: 80-16351.

Theses

Marelić, N. (1998). *Kineziološka analiza karakteristika ekipne igre odbojkaša juniora*. [Kinesiological analysis of the junior volleyball team play characteristics. In Croatian.] (Unpublished doctoral dissertation, University of Zagreb) Zagreb: Fakultet za fizičku kulturu Sveučilišta u Zagrebu.

Horvatin-Fučkar, M. (2002). *Povezanost ritma i uspjeha u sportskoj i ritmičkoj gimnastici.* [Relationship between rhythm and success in artistic gymnastics and rhythmic gymnastics. In Croatian.] (Unpublished Master's thesis, University of Zagreb) Zagreb: Kineziološki fakultet Sveučilišta u Zagrebu.

Manuscripts that do not meet the requirements set in the Guidelines will be immediately returned to the authors for corrections. During the revision of the manuscript, the Editor will contact the first author or the one that is in charge of correspondence.

Tables and figures

Tables and figures should be placed at the end of the manuscript, in one document. The position of tables and figures in the text should be indicated with the words ''Insert Table 1 here''.

Tables should be numbered in the order in which they occur in the text and referred to as "Table 1", for example. Each table should be accompanied by a short title. Figures (e.g. Figure 1), include photographs (either as camera-ready glossy prints or digital photographs of at least 300 dpi – format .tiff or .jpeg; orientation – top and bottom – should be denoted on the reverse side), drawings, graphs, diagrams, X-ray examinations (should be submitted as photocopies). Figures should be prepared in any vector software and open for editing (do not send illustrations in picture format, please). Each figure must have a caption. The pictures and drawings that are not originals should contain the name of the book or journal reference.

Reviews of books

Reviews of books are usually written at the invitation of the Editorial Board of Kinesiology. The Editorial Board generally defines the length of the review. The author of a review should answer the following questions: should the book have been published, is this book better or worse than other similar ones, if these do exist, and who this book can be useful for. Elements of the review should follow this logical order – asking questions, analysis of the arguments "for" and "against" and answers to the questions.

Style and language

The Editorial Board accepts manuscripts written in English only. The language of Kinesiology is either American English or British English. Manuscripts may be rejected if written in poor English. The author is fully responsible for the style (formal, unbiased in any sense), language, and content of the paper. Yet, the Editorial Board has the right to comment on the form and language of the paper before it is accepted for publication. A good, standard command of grammar is expected in written English. Please, avoid non-standard abbreviations.

Copyright notice

PEER REVIEWERS IN 2023

Abdossaleh Zar – Department of Sport Science, School of Literature and Humanities, Persian Gulf University, Boushehr, Iran

Adrián Escudero-Tena – University of Extremadura, Badajoz, Spain

Aki-Matti Alanen – Faculty of Kinesiology, Sport Injury Prevention Research Centre, University of Calgary, 2500 University Drive NW, Calgary, AB, T2N 1N4, Canada

Alberto Filgueiras – Psychological Sciences, University of Gloucestershire, School of Natural, Social and Sport Sciences, QU214, Francis Close Hall Campus, Swindon Road, Gloucestershire, Cheltenham, GL53 7JX, UK

Aldo Vasquez Bonilla – Faculty of Sports Sciences, University of Extremadura, Cáceres, Spain

Alexandra Pizzera – German Sport Univ Cologne, Inst Psychol, Sportpark Mungersdorf 6, D-50933 Cologne, Germany

Ali Pashabadi – Department of Motor Behavior, Faculty of Sport Sciences, Kharazmi University, Tehran, 1571914911, Iran

Alireza Rabbani – Department of Exercise Physiology, Faculty of Sport Sciences, University of Isfahan, Isfahan, Iran

Ardalan Shariat – Department of Digital Health, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran

Asier Santibañez-Gutierrez – Department of Physical Education and Sports, University of the Basque Country, Spain; Applied Bioenergetics Lab, University of Novi Sad, Serbia

Ben Hunter – School of Life and Medical Sciences, University of Hertfordshire, Hatfield, UK; School of Human Sciences, London Metropolitan University, London, UK

Berkcan Boz – Faculty of Sport Sciences, Department of Physical Education and Sport, Ege University, 35040, İzmir, Turkey

Bingnan Gong – Institute of Physical Education and Training, Capital University of Physical Education and Sports, Beijing, China; Facultad De Ciencias De La Actividad Física Y Del Deporte, Universidad Politécnica De Madrid, Madrid, Spain

Bojan Jošt – University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

Boon Chong Kwok – Clinical Pilates Family Physiotherapy

Bülent Kilit – Physical Education and Sports School, Hitit University, Çorum, Turkey

Carlos Artemio Favela Ramírez – Instituto Tecnológico de Sonora México

Catarina Santos – Faculty of Sports Science and Physical Education, University of Coimbra, 3040-256 Coimbra, Portugal

Cem Kurt – Kirkpinar Sport Sciences Faculty, Trakya University, Edirne, Turkey

Christos Mourtzios – Department of Physical Education and Sport Science, Democritus University of Thrace, Greece

Cristian Yanez – Fitness Academy, Bogotá, Colombia

Damir Knjaz – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Damir Sekulić – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Danica Janicijevic – Faculty of Sports Science, Ningbo University, Ningbo, ZJ, China; Research Academy of Human Biomechanics, Affiliated Hospital of Medical School of Ningbo University, Ningbo University, Ningbo, ZJ, China

Daniel Castillo – Faculty of Education, University of Valladolid, 42004, Soria, Spain

Danijel Jurakić – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Danilo Fonseca Leonel – Federal University of Paraná (UFPR); Federal University of Jequitinhonha and Mucuri Valleys (UFVJM), Diamantina, Minas Gerais, Brazil

Dorica Šajber – University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

Dustin Oranchuk – Sport Performance Research Institute New Zealand (SPRINZ), Auckland University of Technology, 17 Antares Place, Rosedale, Auckland, 0632, New Zealand

Ekaitz Dudagoitia Barrio – Faculty of Sports Sciences, University of Murcia, Murcia, Spain; Exercise and Rehabilitation Sciences Laboratory, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile

Elijah Gitonga Rintaugu – Department of Recreation & Sports Management, Kenyatta University, Kenya

Elto Legnani – Federal University of Technology, Paraná/Brazil (UTFPR), Brazil

Fabian Alberto Romero Clavijo – Institut National du Sport du Québec, Montreal, Canada; Sport Studies Department, Bishop’s University, Sherbrooke, Canada

Feng Li – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Flávia Évelin Bandeira Lima – State University of Northern Paraná, Jacarezinho-PR, Brazil

Francisco Javier Robles Palazón – University of Murcia, Murcia, Spain

Francisco Tomás González-Fernández – Department of Physical Education and Sport, Faculty of Education and Sport Sciences, Campus of Melilla, University of Granada, Melilla 52006, Spain

Georgia Allen – Northumbria Univ, Dept Sport Exercise & Rehabil, Newcastle Upon Tyne, Tyne & Wear, England

Gibson Moreira Praça – Department of Sports, Federal University of Minas Gerais, Belo Horizonte, Brazil

Gustavo De Conti Teixeira Costa – Campus Samambaia, Universidade Federal de Goiás, Goiânia 74690-900, Brazil

Henri Tilga – Institute of Sport Sciences and Physiotherapy, University of Tartu, Ujula 4, Tartu, 51008, Estonia

Hongyou Liu – South China Normal University, School of Physical Education & Sports Science, Guangzhou 510006, Guangdong, Peoples Republic of China

Iker Madinabeitia – Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain

Irem Kavasoğlu – Department of Sport Management, Faculty of Sport Sciences, Cukurova University, Adana, Turkey

Iván Peña-González – Sports Research Centre, Miguel Hernández University, Elche, Spain

Jernej Kapus – University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

João B. Martins Martins – Centre for Research, Education, Innovation and Intervention in Sport, Faculty of Sport of the University of Porto, Porto, Portugal

Joel Mason – Department of Human Movement Science and Exercise Physiology, Institute of Sport Science, Friedrich Schiller University Jena, Seidelstraße 20,07749, Jena, Germany

José Miguel Briceño Torres – School of Physical Education and Sports, University of Costa Rica, Costa Rica

Josu Ascondo – Physical Education and Sport Department, Faculty of Education and Sport, University of the Basque Country, UPV/EHU, 01007 Vitoria-Gasteiz, Spain

Jovana Trbojević Jocić – Department of Social Sciences, Matica Srpska, Novi Sad, Serbia

Juan Carlos Pastor-Vicedo – EDAF Group, Didactics of Musical, Art, and Physical Education Department, Faculty of Education, University of Castilla-La Mancha, Albacete, Spain

Julio Calleja-Gonzalez – Physical Education and Sports Department,Faculty of Education and Sport, University of the Basque Country (UPV/EHU), Vitoria, Spain

Katarzyna Sterkowicz-Przybycień – Department of Gymnastics and Dance, Institute of Sport Sciences, University of Physical Education in Krakow, Poland

Lana Jurčec – University of Zagreb, Faculty of Teacher Education, Zagreb, Croatia

Lana Ruzic – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Luca Paolo Ardigò – School of Exercise and Sport Science, Department of Neurosciences, Biomedicine and Movement Sciences, University of Verona, Verona, Italy

Lucija Milčić – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Luis Teba Del Pino – Physical Performance Sports Research Center (PPSRC), Universidad Pablo Olavide Sevilla, 41013 Sevilla, Spain

Luiz Henrique Palucci Vieira – MOVI-LAB Human Movement Research Laboratory, School of Sciences, Graduate Program in Movement Sciences, Physical Education Department, UNESP São Paulo State University, Av. Eng. Luís Edmundo Carrijo Coube, 2085 - Nucleo Res. Pres. Geisel, Bauru, SP, 17033-360, Brazil

Mahmoud Elsayed – Banhā University, Faculty of Physical Education, Banhā, Egypt

Maria Garcia Perujo – Consejería de Educación, Juventud y Deportes de Canarias, Spain

Marija Rakovac – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Mário Espada – Escola Superior de Educação, Instituto Politécnico de Setúbal, 2914-504 Setúbal, Portugal; Life Quality Research Centre (CIEQV-Leiria), 2040-413 Rio Maior, Portugal; CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, 1499-002 Lisboa, Portugal

Marko Erceg – University of Split, Faculty of Kinesiology, Split, Croatia

Matic Sašek – University of Ljubljana, Faculty of Health Sciences, Ljubljana, Slovenia

Matija Jandric – PhD candidate at University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Melanie E. Perreault – SUNY Coll Brockport, Dept Kinesiol Sport Studies & Phys Educ, 350 New Campus Dr, Brockport, NY 14420, USA

Mesa Rahmi Stephani – Faculty of Sport and Health Education, Universitas Pendidikan Indonesia, Bandung, Indonesia

Miloš Milošević – Faculty of Physical Education and Sports Management, Singidunum University, Belgrade, Serbia

Muhammad Azam – Government College University Lahore, Pakistan

Musa Mathunjwa – Department of Human Movement Science, University of Zululand, KwaDlangezwa 3886, South Africa

Nataša Zenić Sekulić – University of Split, Faculty of Kinesiology, Split, Croatia

Nemanja Lakicevic – University of Palermo, Palermo, Italy

Nicholas Joel Ripley – Human Performance Laboratory, University of Salford, Salford M5 4BR, UK

Nikola Prlenda – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Nikola Todorovic – Applied Bioenergetics Lab, University of Novi Sad, Serbia

Nuno André Nunes – Department of Sport and Health, Solent University, Southampton, UK

Olcay Mulazimoglu – Faculty of Sports Sciences, Mugla Sitki Kocman University, Mugla, Turkey

Paula Debien – Faculty of Physical Education and Sports, Federal University of Juiz de Fora, Juiz de Fora, Brazil

Peter Tierney – School of Public Health, Physiotherapy and Sports Science, University College Dublin, Dublin, Ireland

Philip Prins – Department of Exercise Science, Grove City College, Grove City, PA, USA

Rachel Salyer – Department of Medicine, School of Medicine, West Virginia University, Morgantown, West Virginia, USA

Rafael Oliveira – Life Quality Research Centre (LQRC—CIEQV, Leiria), Complexo Andaluz, Apartado, 2040-413 Rio Maior, Portugal; Sports Science School of Rio Maior–Polytechnic Institute of Santarém, 2040-413 Rio Maior, Portugal; Research Center in Sport Sciences, Health Sciences and Human Development, 5001-801 Vila Real, Portugal

Rea Fulgosi-Masnjak – University of Zagreb, Faculty of Education and Rehabilitation Sciences, Zagreb, Croatia

Reza Abdollahipour – Department of Natural Sciences in Kinanthropology, Faculty of Physical Culture, Palacký University Olomouc, Olomouc, Czech Republic

Ricardo Berton – School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil

Robert Podstawski – Department of Physiotherapy, Faculty of Physiotherapy, University of Warmia and Mazury in Olsztyn, Olsztyn, Poland

Roger Font Ribas – Barça Innovation Hub, FC Barcelona, Barcelona, Spain; Research Group in Tecnologia Aplicada a l’Alt Rendiment i la Salut (TAARS), Tecnocampus, Department of Health Sciences, Pompeu Fabra University, Mataró, Spain; GRCE Research Group, National Institute of Physical Education of Catalonia (INEFC), Barcelona, Spain

Saša Vuk – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Sotirios Drikos – School of Physical Education and Sport Science, National Kapodistrian University of Athens, Athens, Greece

Steven Machek – California State University, Monterey Bay, Seaside, California, USA

Tatjana Trošt Bobić – University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Tiago Fernandes – University of Porto, Faculty of Sport, Center for Research Innovation & Interventions in Sport CIFI2D, R Dr Placido da Costa 91, P-4200450 Porto, Portugal

Tomislav Okičić – Faculty of Sport and Physical Education, University of Niš, Niš, Serbia

Veysel Temel – Physical Education and Sports High School, Karamanoglu Mehmetbey Üniversitesi, Karaman, Turkey

Victoria Gottwald – Institute for the Psychology of Elite Performance, School of Sport, Bangor University, Bangor, Gwynedd, Wales, UK

Craig Whitworth-Turner – Department of Athletics, University of Pennsylvania,Philadelphia, PA, USA

Yago Costa – Physical Education Department, Federal University of Paraiba, Brazil

Yaiza Taboada-Iglesias – Galicia Sur Hlth Res Inst IIS, Educ Phys Act & Hlth Res Grp Gies10 DE3, Sergas Uvigo, Spain

Zihong He – Biology Center, China Institute of Sport Science, China

Zuzana Kovacikova – UPJŠ - Pavol Jozef Šafárik University, Košice, Slovakia

Zvonimir Šatalić – University of Zagreb, Faculty of Food Technology and Biotechnology, Zagreb, Croatia

Žiga Kozinc – University of Ljubljana, Faculty of Health Sciences, Ljubljana, Slovenia