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), kicking ball distance (low-effort = control = moderate-effort), and throwing 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, Nassis, and Rebelo (2015) concluded that strength training contributes to enhance 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 training routine of contemporary 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 enhance 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 during 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 with the squat exercise and also with 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.

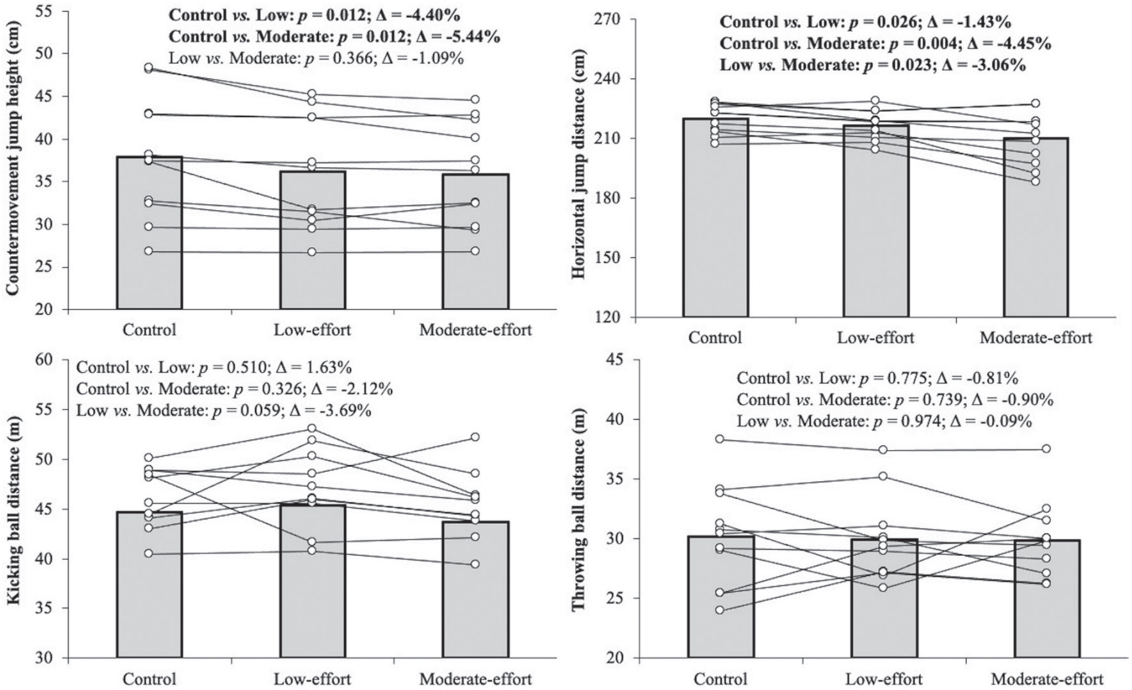

Figure 1. Individual values and comparisons of countermovement jump height (upper-left panel), horizontal jump distance (upper-right panel), kicking distance (lower-left panel), and throwing distance (lower-right panel) between the control, low-effort, and moderate-effort training protocols.

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