EFFECTS OF CONCURRENT ECCENTRIC OVERLOAD AND HIGH-INTENSITY INTERVAL TRAINING ON TEAM SPORTS PLAYERS' PERFORMANCE

Javier Sanchez-Sanchez[1], Oliver Gonzalo-Skok[1,2], Manuel Carretero[1], Adrian Pineda[3], Rodrigo Ramirez-Campillo[1,4], and Fábio Yuzo Nakamura[1,5]

[1]Research Group Planning and Assessment of Training and Athletic Performance, Pontifical University of Salamanca, Salamanca, Spain,
[2]San Jorge University, Zaragoza, Spain,
[3]Santiago de Compostela Fut-Sal, La Coruña, Spain,
[4]Department of Physical Activity Sciences, Research Nucleus in Health, Physical Activity and Sport, University of Los Lagos, Osorno, Chile,
[5]Department of Medicine and Aging Sciences, "G. d'Annunzio" University of Chieti-Pescara, Italy

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Abstract:

The aim of the study was to compare the effects of an in-season five weeks of high-intensity training (HIT) with a concurrent HIT eccentric overload training (CT) program on male amateur team-sports players' fitness performance. Twenty-two athletes were randomly assigned to either HIT (n=10) or CT (n=12). Both groups completed a HIT program. The CT group also completed two-three sets of six repetitions of eccentric overload training. Before and after training, performance was assessed for change of direction ability (COD), repeated sprint ability for best time (RSA_b), mean time (RSA_m) and slowest time (RSA_s), jumping, and shuttle-run performance. Within-group analyses in both groups showed substantial better scores on COD, RSA_b and RSA_m and shuttle-run performance. Between-group analyses showed greater improvements in COD, RSA_b, RSA_m, RSA_s, and jumping after the additional CT compared to solely HIT. In conclusion, compared to HIT alone, concurrent eccentric overload and HIT training within the same session improved COD, RSA, jump, and shuttle-run performance in basketball and soccers amateur players.

Key words: *repeated sprint, maximal aerobic power, resistance training, change of direction, plyometrics, basketball, soccer*

Introduction

In team sports, players are required to repeatedly perform brief high-intensity actions (HIAs) such as sprints, accelerations-decelerations, turns, changes of direction (CODs) and jumps (Ben Abdelkrim, El Fazaa, & El Ati, 2007; Stolen, Chamari, Castagna, & Wisloff, 2005). For example, during a basketball match, a short sprint takes place every 21 to 39 s, while a HIA is repeated every 10 to 20 s (Ben Abdelkrim, Castagna, El Fazaa, & El Ati, 2010; Ben Abdelkrim, et al., 2007). The ability to maintain HIAs for the entire match is important in soccer (Gabbett, & Mulvey, 2008) and basketball (Castagna, et al., 2007) alike. However, decrements in HIAs, mainly at the later stages of matches, have been reported (Ben Abdelkrim, et al., 2007).

Several physiological and mechanical factors may mediate performance decrements in HIAs during team sports matches (Mendez-Villanueva, Hamer, & Bishop, 2008). Of note, players with a greater fatigue-resistance perform HIAs more frequently, with short rest intervals in competition (Carling, Le Gall, & Dupont, 2012). High-intensity interval training has been recommended to enhance fatigue-resistance and repeated HIA ability in team sports athletes (Buchheit, Mendez-Villanueva, Delhomel, Brughelli, & Ahmaidi, 2010a; Buchheit, Mendez-Villanueva, Quod, Quesnel, & Ahmaidi, 2010b; Gonzalo-Skok, et al., 2016).

Besides improving the fatigue-resistance ability, the development of HIA-related abilities is also important within a team sports settings, as a great percentage of goals in soccer (i.e., 83%), for example, are preceded by at least one powerful action of the scoring or the assisting player (Faude, Koch, & Meyer, 2012). Development of the ability to perform HIAs through eccentric overload training (EOT) has become very common (Nadal & Carlin, 2011), improving COD speed/kinetics, jumping and sprinting (de Hoyo, et al., 2016; Gonzalo-Skok, et al., 2017; Tous-Fajardo, Gonzalo-Skok, Arjol-Serrano, & Tesch, 2016), besides its role in injury prevention (Askling, Karlsson,, & Thorstensson, 2003; de Hoyo, et al., 2015). Therefore, training strategies that focus on improving HIAs (i.e., EOT) and fatigue-resistance (i.e., high-intensity interval training), may enhance players' performance.

A common team sports weekly practice includes both high-intensity interval training and strength/power training in a concurrent manner (Buchheit & Laursen, 2013a). Accordingly, concurrent high-intensity strength (i.e., EOT) and high-intensity interval training has been recently proposed as an effective training method to minimize the interference phenomenon and enhance the player's overall performance (Silva, Nassis, & Rebelo, 2015). Notably, in some instances strength-power training can hamper endurance adaptations (Docherty & Sporer, 2000). However, to our knowledge, no studies have analyzed the effects of concurrent EOT and high-intensity interval training in team sports players in comparison to high-intensity interval training alone. Therefore, the aim of the present study was to compare the effects of 5 weeks of high-intensity interval training (HIT) program with a concurrent HIT plus EOT (CT) program on amateur team-sports players' repeated sprint ability (RSA), COD ability, jumping and shuttle-run performance.

Methods

Subjects and experimental design

Initially, 24 male amateur team-sports players (age = 22.5±2.2 years; body height = 175.8±7.1 cm; body mass = 72.6±9.1 kg) volunteered to participate in a five-week training study during the in-season. Athletes were competing at regional level in soccer (n=12) or basketball (n=12). Using a randomized controlled study design, half of the players from each sport were divided into HIT (n=10) or CT (n=12). Two athletes originally randomized to the HIT group did not complete the intervention.

Athletes participated in four-six hours of technical-tactical training plus one competitive match per week. None of them had already participated in systematic HIT or CT. Prior to the commencement of the study, participants completed a health questionnaire to document that they were free of cardiovascular disease, physiological disorders, or any other illness. Written informed consent was received from all the subjects after a brief explanation about the aims, benefits, and risks involved in this investigation. The present study is in accordance with the ethical standards from the latest version of the Declaration of Helsinki and the protocol was fully approved by the Clinical Research Ethics Committee.

Testing procedures

Physical fitness tests were carried out on an indoor basketball court on two different days of the week preceding the intervention and the week immediately following the completion of the last training session. On the first day, the Illinois test and the RSA test were administered. On the second day, a countermovement jump (CMJ) test for maximal height and the 20-m shuttle run test were performed. Every assessment session took place under similar environmental conditions and at the same time of the day (5-8 p.m.), thus minimizing circadian rhythms variations. Players were asked not to perform intense exercise at least 48 hours before testing and to consume their last meal three hours before the scheduled test time.

The COD ability was examined using the Illinois test (Figure 1), as previously described (Ramirez-Campillo, et al., 2016). The test was used to determine the ability to accelerate, decelerate, turn in different directions, and run at different angles (Sheppard & Young, 2006). The Illinois test is set up with four cones forming an area 10-m long and 5-m wide. A cone was placed at each point (a) to mark the start, (b and c) to mark the turn spots, and (d) to mark the finish. Another four cones were placed in the center of the testing area, 3.3-m from each other. The test was conducted indoors on a wooden running surface. The athletes started on the floor, facing the floor, and begun when they were ready. The athletes completed the circuit as fast as possible. Test time was measured with photoelectric cells (DSD Laser System, and software Sport test v3.2.1), positioned at the finish point, 1-m over the floor (i.e., athletes hip level). Subjects were given

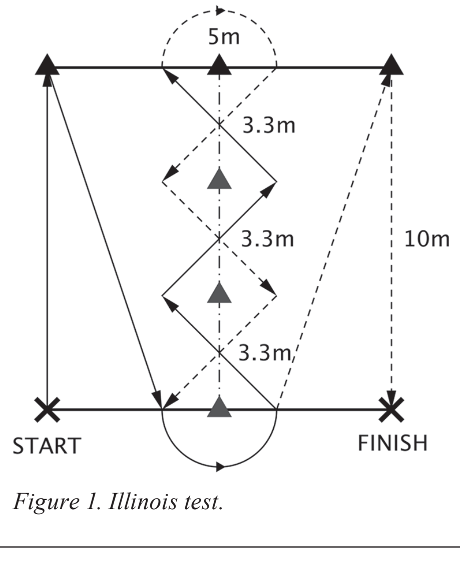

Figure 1. Illinois test.

two practice trials performed at half speed after a thorough warm-up to familiarize with the circuit and timing device. Two trials were completed, and the best performance trial was used for the subsequent statistical analysis. Three minutes of rest were allowed between the trials. Times were measured to the nearest 0.001 second.

The RSA test comprised six bouts of two 15-meter sprints with 180º COD and 30 seconds of passive recovery between bouts (Buchheit, et al., 2008). Prior to the RSA test, participants executed a preliminary single shuttle-sprint which was used as the criterion score (Wong, Chaouachi, Chamari, Dellal, & Wisloff, 2010). Subjects rested 5 minutes before starting the RSA test. If performance in the first sprint was worse than the criterion score (i.e., an increase of 2.5% in time), the test was finished, and this participant was required to rest for 5 minutes before re-starting the RSA test. Participants commenced each sprint from a standing start position with their front foot placed 0.5 m behind the starting/finishing timing gate (DSD Laser System and software Sport test, v3.2.1). The best (RSA_b), the mean (RSA_m) and the slowest (RSA_s) times and the percentage of decrement (%Dec) in sprint time were retained for subsequent analysis. The %Dec was calculated using the following formula:

$[100 \cdot (\text{total sprint time} / RSA_b)] - 100$,

as it was considered the most valid and reliable calculation to quantify fatigue in RSA testing (Glaister, Howatson, Pattison, & Mcinnes, 2008). Verbal encouragement was provided during each sprint.

Jumping height was calculated through flight time (Globus Ergo System®, Codogne, Italy) in a vertical CMJ. Visual inspection confirmed that landing occurred without any knee flexion with the hands kept at the hips/waist. Each player performed two jumps with two minutes of passive recovery between jumps. The best jump was selected for subsequent analysis.

The 20-m shuttle run test is an incremental running test. This test began with an initial running speed of 8.5 km/h followed by a consecutive speed increase of 0.5 km/h each minute until exhaustion. The participants adjusted their running speed to match auditory signals (Sony ENG203® speakers) set to correspond to 20-m shuttle runs. The end of the test was taken when players failed to reach the next line in the required time two successive times. Throughout the test, heart rate (HR) was recorded beat to beat (Polar® Team System-2, Kempele, Finland). Moreover, the last period completed in the test was also used for analysis.

Training protocol

Participants in both groups performed two HIT sessions a week (Monday and Wednesday or Tuesday and Thursday) always in the afternoon (5-8 p.m) during 5 weeks. Experienced researchers controled every training session. The HIT sessions lasted 26 minutes and were completed on an athletic track. The HIT was compounded of 6 minutes of warm-up (low-intensity running and accelerations) and two sets of eight repetitions of linear running for 30 seconds at 90-100% of the maximum heart rate (HR_{max}) interspersed with 30 seconds of active recovery between repetitions (60% HR_{max}) and 3 minutes of passive recovery between sets. The HR was continuously monitored (Polar® RS-400). The HR_{max} achieved during the 20-m shuttle run test (described below) determined running intensity.

The CT group performed several eccentric overload iso-inertial drills in addition to HIT. EOT was always executed before the HIT sessions. Between the EOT and HIT sessions, participants passively recovered for 10 minutes. EOT consisted of backwards lunges and unilateral hamstrings "kicks" using an iso-intertial portable conical pulley (Versapulley®, Costa Mesa, CA; Inertia 0.27 kg/m^2) and half-squats employing the kBox3 (Exxentric AB®, Bromma, Sweden; Inertia 0.05 kg/m^2). The exercise load was progressively increased from two sets of six repetitions performed during the first five training sessions to three sets of six repetitions during the following five training sessions. During the training on the flywheel iso-inertial devices, players were encouraged to perform the concentric phase as fast as possible, while delaying the braking action to the last third of the eccentric phase. Between sets and exercises, one and two minutes of passive recovery were provided, respectively.

Statistical analysis

Data are presented as M ± standard deviation (SD). All data were first log-transformed to reduce bias arising from non-uniformity error. The standardized difference or effect size (ES), with 90% of confidence limits (CL) in the selected variables, was calculated using the pooled pre-training SD. Threshold values for Cohen ES statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large) (Hopkins, Marshall, Batterham, & Hanin, 2009). For within/between-group comparisons, the chances that the differences in performance were better/greater (i.e., greater than the smallest worthwhile change, SWC [.2 multiplied by the between-subject standard deviation, based on the Cohen's *d* principle]), similar or worse/smaller were calculated. Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: <1%, almost certainly not; >1-5%, very unlikely; >5-25%, unlikely; >25-75%, possible; >75-95%, likely; >95-99%, very likely; and >99%, almost certain (Hopkins, et al., 2009). If the chance of having beneficial/better or detrimental/poorer performances was both >5%, the true difference was assessed as unclear. Otherwise, we interpreted that change as the observed chance (Hopkins, et al., 2009). The Pearson product-moment correlation coefficient was used to determine the relationship between different variables. The following criteria were adopted for interpreting the magnitude of correlation (r) between tests measures: ≤.1, trivial; >.1-.3, small; >.3-.5, moderate; >.5-.7, large; >.7-.9, very large; and >.9-1.0, almost perfect (Hopkins, et al., 2009). If the 90% CL overlapped small positive and negative values, the magnitude of the correlation was deemed unclear; otherwise the magnitude was deemed to be the observed magnitude (Hopkins, et al., 2009). The spreadsheet of Hopkins (Hopkins, 2012) was also used to determine the change in the mean between trials and the typical error of measurement, expressed as a coefficient of variation (CV, %). A CV of 5% was set as the criterion for reliability.

Results

The CV values were 2.1% (90% CL: 1.8; 2.7%), 1.3% (90% CL: 1.1; 1.8%), 0.8% (90% CL: .7; 1.1%), 1.5% (90% CL: 1.2; 2%), 28.3% (90% CL: 22.1; 39.8%), 3.3% (90% CL: 2.7; 3.9%) and 6.8% (90% CL: 5.3; 9.6%), for COD ability, RSA_b, RSA_m, RSA_s, %Dec, CMJ and 20-m ST, respectively.

Within-group changes

The best and the mean time in the RSA test, the Illinois test, and the 20-m shuttle run test were substantially improved in both the CT and HIT groups (Table 1). Additionally, a substantial improvement was found for RSA_s, %Dec, and CMJ in the CT group (Table 1).

Between-group changes

Results from the between-group analysis are illustrated in Figure 2. The differences between the groups in relative improvements showed substantially greater improvements after CT than HIT for RSA_b (2.6% [.7; 4.5]; QC: 87/13/0%), RSA_m (3.6% [1.1; 6.0]; QC: 93/7/0%), RSA_s (5.1% [1.1; 8.9]; QC: 94/6/1%), %Dec (49.3 [-3.6; 131.5]; QC: 87/10/3%), Illinois test time (3.5% [-.3; 7.2]; QC: 85/13/2%) and CMJ height (7.5% [2.7; 12.4]; QC: 93/7/0%).

Relationships between physical performance improvements

When data of both groups were pooled, the training-induced RSA_m changes were very largely and largely correlated with changes in RSA_b (r=.77; CL 90%: .57; .90) and RSA_s (r=.68; CL 90%: .43; .85), respectively. Interestingly, the %Dec changes

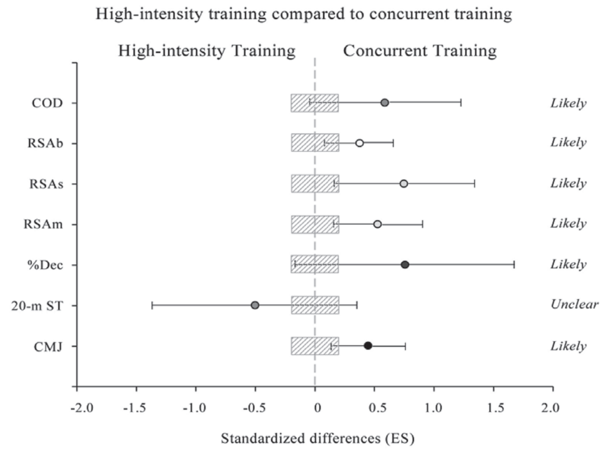

Figure 2. Effects of high-intensity training compared to concurrent training.

Table 1. Effects of concurrent eccentric overload (CT; n=12) and high-intensity interval training (HIT; n=10) on repeated sprint ability, change of direction ability, jumping and shuttle-run performance before (pre) and after (post) five weeks of training

		Pre-test	Post-test	% (CL90%)	ES (CL90%)	Outcome
Illinois test (s)	CT	17.9 ± 1.0	16.9 ± 1.0	5.6 (3.7; 7.6)	1.01 (.65; 1.36)	Almost certain
	HIT	18.8 ± .9	18.3 ± 1.4	2.3 (.0; 4.6)	.42 (.00; .84)	Likely
RSA_b (s)	CT	6.07 ± .41	5.86 ± .37	3.5 (2.2; 4.9)	.51 (.32; .71)	Very likely
	HIT	5.93 ± .21	5.79 ± .21	2.4 (.9; 4.0)	.59 (.20; .97)	Very likely
RSA_s (s)	CT	6.47 ± .41	6.20 ± .39	4.1 (1.1; 6.9)	.63 (.16; 1.09)	Likely
	HIT	6.27 ± .27	6.30 ± .44	-.3 (-3.7; 3.0)	-.05 (-.74; .63)	Unclear
RSA_m (s)	CT	6.29 ± .41	6.01 ± .37	4.4 (2.6; 6.3)	.67 (.38; .96)	Very likely
	HIT	6.08 ± .21	5.97 ± .21	1.9 (1.3; 2.4)	.48 (.34; .62)	Almost certain
%Dec (%)	CT	3.55 ± 1.65	2.59 ± 0.83	23.9 (7.5; 37.3)	.58 (.17; .99)	Likely
	HIT	2.55 ± 1.14	3.15 ± 2.12	-13.7 (-70.9; 24.3)	-.23 (-.96; .50)	Unclear
20-m ST (periods)	CT	8.58 ± 1.06	9.54 ± 1.01	11.4 (7.4; 15.5)	.80 (.53; 1.07)	Almost certain
	HIT	9.55 ± 1.94	11.40 ± 1.66	20.5 (7.2; 35.4)	.82 (.30; 1.33)	Very likely
CMJ (cm)	CT	35.3 ± 5.0	37.9 ± 5.4	7.2 (4.3; 10.3)	.46 (.28; .64)	Very likely
	HIT	35.3 ± 5.5	35.0 ± 4.5	-.3 (-3.5; 3.0)	-.02 (-.22; .18)	Likely trivial

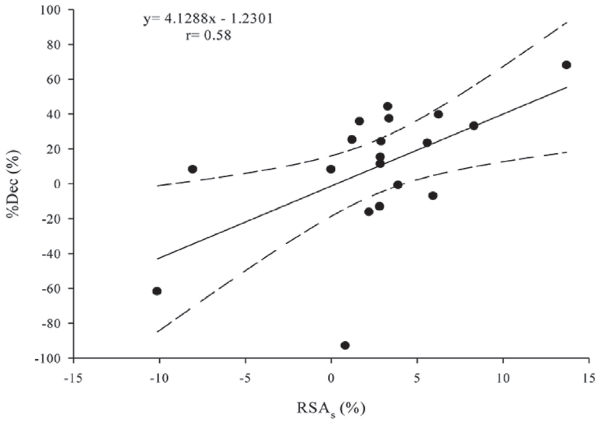

Figure 3. Relationship between relative changes in percentage decrement (%Dec) and relative changes in the slowest time (RSA$_s$) of the repeated sprint ability test. Solid line represents best-fit and doted lines 95% of confidence interval. Note that negative values indicate improved performance.

were positively correlated with changes in RSA$_s$ (r=.58; CL 90%: .25; .79) (Figure 3), while a negative relationship was found between the former and changes in RSA$_b$ (r=-.45; CL 90%: -.71; -.09).

Discussion and conclusions

The aim of this study was to compare the effects of five weeks of HIT program with a CT program on amateur team-sports players' RSA, COD ability, jumping and shuttle-run performance. The main findings were as follows: i) five weeks of CT simultaneously induced small to moderate improvements in COD, RSA, CMJ and 20-m ST; ii) RSA$_m$ adaptations were associated with better RSA$_b$, rather than enhancements in 20-m ST; iii) CT elicited substantially better results than HIT in all performance measurements, with the exception of the 20-m ST, where unclear differences were reported. All training effects were greater than the CV presented in the reliability analysis. Hence, it is worth noting that all changes should be considered meaningful performance improvements.

Regarding the effects of CT on COD ability, a previous study showed a small effect (ES=.43) in a group of professional Swedish soccer players after five weeks of pre-season training (McGawley & Andersson, 2013). It seems that EOT included during CT may improve COD ability as eccentric strength is one of the most important determinants of its performance (Girard, et al., 2011; Jones, Bampouras, & Marrin, 2009; Tous-Fajardo, et al., 2016). This partially may help to explain the greater COD ability improvement in the CT group compared to the HIT group, especially considering that the influence of strength on COD performance depends heavily on the specific COD test used. In this sense, strength and power in the lower limbs become more important with sharper turns and increased number of direction changes (Young, James, & Montgomery, 2002), as in the COD test used in our study (i.e., Illinois test). However, this issue remains speculative, as neither eccentric strength nor direct measures of power were obtained in this study.

The RSA improvements found in the present study after both the HIT and CT training (ES=.48 to .67) are within the range (ES=.23 to 1.63) of those previously published (Ferrari Bravo, et al., 2008; Gonzalo-Skok, et al., 2016a; Suarez-Arrones, et al., 2014). Even though the HIT program was capable to substantially improve RSA$_b$ and RSA$_m$, the addition of EOT provided a likely better effect for all RSA measures than the solely execution of HIT. As previously reported, RSA is mostly determined by RSA$_b$ and the ability to tolerate repeated sprints with incomplete recovery (Bishop, Girard, & Mendez-Villanueva, 2011). With this in mind, compared to HIT, the inclusion of CT may simultaneously have improved several determinant factors of RSA (muscular and neural) (Bishop & Spencer. 2004). However, possible underlying mechanisms related to these findings remain speculative.

A very strong relationship was observed between the RSA$_b$ and RSA$_m$ enhancements (r=.77; CL 90%: .57; 090), similar to previous studies (Gonzalo-Skok, et al., 2016a; Suarez-Arrones, et al., 2014). On the other hand, while RSA$_s$ and %Dec were not improved (i.e., unclear effects) after HIT training, CT showed a substantial improvement in both variables (ES=.63 and .58, respectively). These enhancements together with the large association observed between the changes in RSA$_m$ and RSA$_s$ (r=.68; CL 90%: .43; .85) and between RSA$_s$ and %Dec (r=.58; CL 90%: .25; .79) all seem to indicate that the ability to resist the sprint-induced fatigue was also enhanced after CT. These results are comparable to those of a previous strength training intervention with short recovery periods between effort bouts (Gonzalo-Skok, et al., 2016a). The potential underlying physiological mechanisms responsible for the improvement were not assessed in this study. However, it has been indicated that improved buffering capabilities may be linked to the ability to tolerate fatigue during repeated high-intensity efforts (Bishop, et al., 2011).

Both training programs improved 20-m ST performance. Improvement in endurance is common after HIT, even in highly-trained athletes (Buchheit & Laursen, 2013b). Although less studied, previous studies showed VO_{2max} improvements after a CT that combined resistance training and HIT within the same session (Cantrell, Schilling, Paquette, & Murlasits, 2014; Chtara, et al., 2008). However, others have indicated strength interference over endurance improvement (Bishop, Jenkins, Mackinnon, Mceniery, & Carey, 1999; Docherty & Sporer, 2000), especially when strength training was combined with continuous training methods for endurance development (Wong, et al., 2010). However, in our study EOT showed no interference with shuttle-run performance improvement. As such, it seems that HIT (i.e., an intermittent training method for endurance development) may be well suited for combination with strength training methods such as EOT.

Jumping ability was very likely enhanced after CT and trivially affected following HIT. The lack of effect of HIT on CMJ was somewhat expected, as previous findings suggested that HIT was limited to trigger neuromuscular adaptations required to jumping higher (Ferrari Bravo, et al., 2008). Otherwise, the small effect (ES=.46) after CT is within the range of results previously reported (ES=.25 to .77) after the training of both adult and young athletes (Buchheit, et al., 2009; Tous-Fajardo, et al., 2016). Thus, the inclusion of strength training might be fundamental when the aim is to improve vertical jumping height during concurrent training.

Some potential limitations should be acknowledged. Firstly, we did not incorporate physiological measures, thus the underlying mechanisms potentially explaining the observed physical fitness improvements remained to be determined in future research. Secondly, both basketball and soccer players were included in the study, and the same physical fitness tests were applied to them. However, the tests may not reflect equal ecological validity for both types of players. Although in the current study both basketball and soccer athletes were deemed as appropriate to be included in the study in order to increase the statistical power, future studies should look at replication of this intervention in a specific group of athletes from a given sport, including a set of physical fitness tests that better resemble the demands of their specific sport. Thirdly, and related with the previous point, while the levels of physical fitness of those athletes improved, we cannot draw any conclusions regarding changes in their football/basketball performance as these had not been assessed. Fourthly, the improvements following two training regiments were observed in amateur-level athletes and no conclusions regarding the effectiveness of these training regiments should be extended to highly trained professional athletes.

In conclusion, compared to HIT alone, concurrent eccentric overload and HIT training within the same session concurrently improved RSA, COD, jump, and shuttle-run performance. The take-home message is that amateur team-sports players can maximize their in-season physical fitness performance (i.e., COD ability, RSA, jumping, and 20-m shuttle run performance) by including a short-term (i.e., five weeks) CT program into their training schedules, involving two ~30 minutes training sessions per week of EOT (i.e., three lower-body drills, for two-three sets of six repetitions each) together with HIT.

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Correspondence to:
Fábio Yuzo Nakamura, Ph.D.
Department of Medicine and Aging Sciences, "G. d'Annunzio" University of Chieti-Pescara,
Via dei Vestini, 31, 66100 Chieti, Italy
E-mail: fabioy_nakamura@yahoo.com.br

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Authors' contributions

JSS, OGS, FYN and RRC conceived the study design, participated in its design, coordination, helped to draft the manuscript and carried out the statistical analysis. MC and AP applied the programs and assessments and critically reviewed the manuscript. All authors have read and approved the final version of the manuscript and agreed with the order of presentation of the authors.

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