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ORIGINAL ARTICLE

# Impact of Eccentric Exercises on Soccer Players' External Load, Muscle Soreness and Physical Performance: A Comparative Study of Pre and Post-Training Routines

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**Abstract**
This study examined the impact of integrating eccentric bodyweight exercises (Nordic Hamstring and Single Leg Deadlift) into soccer training, before and after training sessions, on players' well-being, external load and physical performance over two successive training sessions. Twenty-one male trained players (23.6 ± 3.7 years, playing experience of 13.3 ± 4.01 years) participated in the study. The study spanned two days of the microcycle (MD-4 and MD-3) over four consecutive weeks, during which the players were subjected to two conditions: eccentric training before or after the MD-4 training (pre-strength and post-strength, respectively). The players' wellness, external load and physical performance (CMJ, 10 m and 30 m-sprint) were assessed in all training sessions. In pre-strength condition, players exhibited a decrease in the CMJ following the eccentric intervention ($P = 0.02$). For the 30 m-sprint, a decline in performance was noted after the soccer training compared to the moments immediately before ($P = 0.04$) and after the eccentric intervention ($P = 0.002$). In the post-strength condition, players reported increased muscle soreness in the following day (MD-3, $P = 0.03$). Additionally, a reduced number of high-intensity accelerations were observed on MD-3 when the eccentric training was performed after MD-4 ($P = 0.04$). The study reveals that jumping and sprinting performance may decrease immediately after eccentric routines. However, while jumping performance may recover after the training, sprinting remains affected. Conversely, conducting eccentric routines after training may influence players' muscle soreness and physical performance on the following day. This study offers valuable insights for optimizing soccer training schedules that incorporate eccentric routines either before or after regular training sessions.

**Keywords** Eccentric training · Microcycle · External load · Sprinting · Jumping · Team sports

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## Introduction

Soccer is characterized by high-intensity intermittent actions, such as jumping, tackling, kicking, turning, and sprinting [31]. The players' capacity to perform some of these actions, such as sprinting, may play a crucial role in goal-scoring situations which may directly impact match outcome [26]. Success in soccer is also associated with players' training consistency and availability on the field [23]. Despite various risks associated with muscle injuries in soccer, muscle-strength imbalances, particularly between agonist and antagonist lower limb muscles groups, have been identified as a significant factor [16]. Indeed, strength training has proven to be an effective method for reducing injury risk in soccer players, especially when incorporating eccentric training (ECC) due to its unique chronic adaptations [6]. Eccentric training leads to improvements in sprint performance and peak eccentric hamstring strength [36],

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which means that incorporating eccentric-based programs can play a major role in optimizing soccer players' physical performance while simultaneously decreasing the total incidence (i.e. per 1000 h of training and matches) of muscle injuries [18].

Among various exercises available to strength and conditioning coaches for implementing eccentric training, the Nordic hamstring exercise (NHE) has emerged as a widely favored choice in amateur and professional levels [21, 37, 42], both because of the simple logistical application (i.e. no additional equipment is required) and its effectiveness in reducing hamstrings injuries [57], which is known to be a major concern in football [22, 24]. The NHE has consistently proven to be effective in enhancing hamstrings strength and sprint performance among male soccer players [36], making it a valuable exercise for injury prevention across different populations and sports [3, 35, 37]. Additionally, the Single Leg Deadlift (SLD) has gained widespread use due to its the significant engagement of hamstring muscles during both concentric and eccentric phases [19]. Reports suggest that both exercises, NHE and SLD, positively impact players' neuromuscular performance and reduce the risk of injuries, potentially complementing each other [9]. Surprisingly, despite of their individual efficacy, no research has explored the combined acute effects of integrating both exercises on players' jumping and sprinting performance, two key capacities in amateur football. Notably, these protocols are not only effective but also practical, time-efficient, and cost-effective, a significant consideration for amateur soccer teams with limited resources for strength training development. Consequently, it is important to explore how amateur players acutely respond to eccentric protocols incorporating both NHE and SLD exercises.

The integration of eccentric-based exercises into regular training schedules is crucial for enhancing players' physical performance and reducing injury risk [23, 55]. However, these protocols are frequently disregarded in soccer training routines [22, 24]. This lack of adherence could be attributed to the unfamiliarity with eccentric contractions, which often lead to elevated muscle soreness, force impairments and muscle damage [50]. This muscle damage typically results from overstretching and disrupted sarcomeres, which can acutely impair the muscle's ability to generate voluntary contraction force [47]. Additionally, compliance with eccentric training may be compromised if the training methodology is inadequate and does not consider important criteria such as progressive load adjustments, training level, and strength training experience [11]. These factors may deter both players and coaches from consistently adopting these strategies throughout the season. Contributing to this issue is the scarcity of research providing guidance on incorporating eccentric training routines into weekly cycles, especially during the in-season period [43]. Nevertheless, incorporating bodyweight eccentric exercises (ECC) in the middle of the micro-cycle session may result in increased muscle damage and soreness, persisting at high levels until the day before the match, which suggests that scheduling these routines at the beginning of the week could prevent impairing players' readiness for the upcoming match [39]. However, limited research has explored whether coaches should plan the strength training before or after the session. Implementing these routines before the training session may guarantee a less fatigued state, but the immediate effects might lead to reduced eccentric strength during training and may increase the risk of muscular injury [38]. Conversely, performing these exercises in a fatigued state (i.e., after training) may be important at long-term to reduce the negative influence of fatigue [54] but could impact players' recovery and readiness for the subsequent session, especially in amateur contexts where players may lack experience in strength training [38, 39]. Addressing this issue could assist coaches in planning strength training for amateur players concerning its timing within the training session, offering practical recommendations on when to incorporate eccentric exercise for maximum benefit, minimizing the risk of overtraining and injury. Moreover, Furthermore, most studies have focused on the effects of eccentric exercises on players' physical performance during specific jumping and sprinting tests, overlooking their potential impact on amateur players' external load during the session. It is conceivable that performing strength training before or after the session could influence not only the immediate session but also the subsequent one. Therefore, this study aimed to investigate the effects of incorporating eccentric bodyweight exercises (NHE and SLD) before and after soccer training sessions (SOT) on amateur players' perceived exertion, perceived fatigue, jump and sprinting performance, and external load across two consecutive training sessions.

## Methods

### Participants

Twenty-one male classified as trained players [44] (age: 23.6 ± 3.7 years; height: 1.71 ± 1.01 m; body mass: 65.2 ± 10.3 kg; playing experience including youth level: 13.3 ± 4.01 years; adult-level experience: 4.1 ± 3.2 years) from one Portuguese regional-level team with no strength training experience participated in this study. All players in the squad took part in the study and participated in each of the different conditions evaluated. Two players were excluded from study due to an injury reported in the month previous to the protocol intervention. Two other players were excluded as result of: (i) being transferred to a new club during the process of data collect; (ii) failing more than one moment of data collection; (iii) goalkeepers were also excluded ($n=3$) due to the different positional requirements. The experiment was conducted during the in-season period (January–February), in which the team had a weekly schedule of 3 field training sessions (~90 to 105-min duration), with an official match in the weekend. All players were informed about the study design, requirements and procedures, and their informed consent was obtained. The present study was developed according to the recommendations proposed by the Declaration of Helsinki. Considering that the data was obtained from regular monitoring of players' during competitive season, no ethical approval was required [61]. Nevertheless, approval from the club was obtained.

## Procedures

A repeated measures design was adopted to explore the effects of the time-period of the ECC using a randomized approach during four MD-4 and four MD-3 testing sessions over 4 consecutive weeks. To inspect the effects of the ECC on the players' perceived fatigue, external load, jumping and sprinting performances, the players were exposed to two experimental settings: (a) ECC prior to the SOT, pre-strength, in which the players performed a specific body-weight strength routine following the warm-up; (b) ECC after the SOT, post-strength, in which the players performed the same ECC routine (see strength intervention section) immediately after the end of the session. Accordingly, while perceive fatigue was monitored before (i.e., Hooper Index) and after the session (i.e., RPE), and external load during each MD-4 and MD-3 sessions, in turn, players' physical assessment was developed at three distinct time periods during the MD-4 session and two periods during the MD-3 session (see Fig. 1): (i) baseline 1, that refers to the first physical assessment moment, performed at the beginning of the MD-4 session after the warm-up in both protocols; (ii) Post-M1, that refers to the second physical assessment moment, which was performed at different timing periods as result of being pre-strength or post-strength. Accordingly, during the pre-strength it consisted in the assessment immediately after the ECC training at the first phase of the training session, while for the post-strength it refers to the measurement immediately after the SOT session ends; (iii) Post-M2, which relates to the third assessment measurement. Accordingly, for the pre-strength it refers to the last assessment on the MD-4, after the session ended, while in the POST-STRENGTH it was performed after the end of the session subsequent to the ECC training; (iv) baseline 2, that refers to the fourth assessment period and performed after the warm-up at the beginning of the session on the MD-3; and (v) Post-M3, that consisted in the fifth measurement, developed at the end of the MD-3 sessions. Thus, while the first three moments (baseline

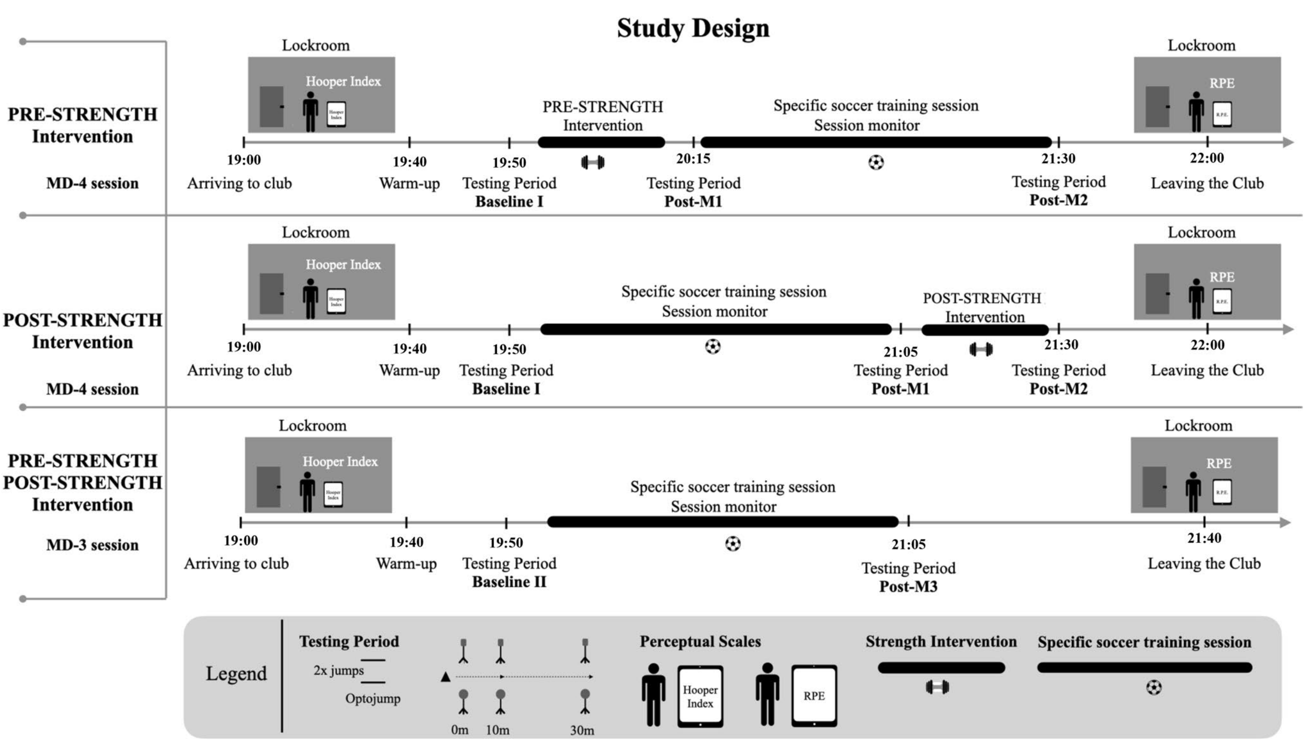


Fig. 1 Schematic representation of protocol timeline

1, Post-M1 and Post-M2) were performed in the MD-4, the second two moments (baseline 2 and Post-M3) were performed during the MD-3 session.

A total of eight testing sessions were used to collect players' data [MD-4 sessions, n = 4, pre-strength (n = 2) and post-strength (n = 2); MD-3 sessions, n = 4, pre-strength (n = 2) and post-strength (n = 2)]. However, prior to the testing period, players were exposed over a one month-period (i.e., 4 sessions) to the strength training intervention for familiarization purposes. In addition, two familiarization sessions (i.e., one for each testing day) were performed to guarantee that players were familiarized with the session structure. On each testing day, as soon as all squad arrived on the locker room, the researcher provided a link with players' names to report either pre-session levels of sleep, stress, fatigue and muscle soreness, or after the session the perceived fatigue. Further, ~ 10-min before the session the players' performed a specific warm-up consisting of 5-min of low intensity running, followed by 3-min of dynamic stretching exercises during and 2-min in which the players performed two sprints at 70% and 80% of their maximal sprinting performance. After that, players were enrolled in the experimental setting. By the end of the session, the researcher provided a new link for the players to report their rate of perceived exertion (RPE).

The MD-4 training structure for each condition (pre-strength, n = 2 and post-strength, n = 2) followed a similar structure. Accordingly, apart from testing situations and the strength training moment that varied according to the present study aim (see Fig. 1), both conditions presented the following structure: a) ~ 20-min small-sided games consisting of Gk + 4vs4 + Gk to emphasize specific principles of play; b) ~ 30-min positional games to emphasize sectorial work (e.g., improve moment coordination between different playing positions and sectors, such as playing an Gk + 4 + 4v4 + 4 + Gk divided by zones to emphasize defensive and midfielder sector movement synchronization); and ended with ~ 25-min competitive small-sided games (e.g., tournament between four teams composed by specific sectors, such as defensive sector vs midfielder sector). Similarly, the MD-3 was also composed by the same structure, which apart from testing situations consisted in: (1) ~ 15-min rondos to emphasize technical patterns, namely ability of the team to stay under possession (e.g., 4vs4 + 3 neutral players); (2) ~ 20-min of positional games emphasizing the team ability to stay on possession based on progressive possession style of play (e.g., 8v8 + 4 neutral players); (3) ~ 20-min sectorial task emphasizing the build-up phase of play consisting in numerical superiority task (e.g., Gk + 8vs6 + 2Gk); (4) ~ 25-min game consisting in Gk + 10vs10 + Gk in regular spaces to develop strategical plan for upcoming match.

## Training

A ~ 15-min time period was used to perform the strength intervention, that consisted of a sequence of two bodyweight exercises focused on lower limbs posterior chain muscles. The first exercise was the NHE, which primarily targets the eccentric action of hamstrings muscles [42]. The NHE technique execution followed previous research guidelines [45]. This exercise have been widely applied as an injury prevention strategy in different populations [3, 35], and it was already shown to enhance muscle strength and running performance in male soccer players [36]. The second exercise was the SLD. Deadlifts are able to promote high levels of activity in the hamstrings [5], with SLD variation being preferable to target hamstrings in both concentric and eccentric phases [19]. The SLD technique execution followed previous research guidelines [19]. These exercises were chosen for their simple application and effectiveness in reducing the risk of hamstring injuries [57].

Before performing the eccentric exercises, a 5-min warm up was conducted, consisting of 2 × 30 m linear low intensity running, 2 × 30 m side run, dynamic stretching for main locomotive lower limb muscles (10 hip adductions, 10 hip abductions, 10 butt kicks, 10 knee raises and 10 straight leg march) and dynamic strength exercises (10 deep squats, and 10 forward lunges) [2].

Players were asked to perform three sets of four reps for each exercise, with SDL performed before NHE. A 60-s interval was allowed between sets and exercises. Participants were instructed to achieve their maximum range of motion in both exercises, with a 3-s duration for the eccentric phase of each repetition. The use of a 3-s eccentric phase was based on players' feedback and performance during the familiarization phase, ensuring all athletes could perform both exercises in a controlled manner. In NHE, players were allowed to use their upper limbs to push off the ground, assisting them in returning to the initial position during the concentric phase.

## Testing

**Rate of Perceived Exertion** The perception of effort was measured using the RPE scale (Borg CR-10 scale) [7]. Players' RPE was collected 30-min after each MD-4 and MD-3 sessions to capture an overall perspective of players' reported effort in the session, by providing to each player a link created on Google form allowing them to individually fulfill the perceived exertion at the same time-period.

**Sleep, Stress, Fatigue and Muscle Soreness Monitor** Players were asked to rate their overall well-being indices 40–30-min prior to the session using the Hooper Questionnaire, that focus on the quality of sleep during previous night, level of stress, rating fatigue and muscle soreness) [33]. For each of these parameters, players were asked to report in a scale ranging from 1 (i.e., very, very low) to 7 (i.e., very, very high) for stress, fatigue and muscle soreness, while 1 (i.e., very, very bad) to 7 (i.e., very, very good) for sleeping quality. These measurements were individually reported by the players on the MD-4 and MD-3, using a specific link created on Google form.

**Jumping Performance (Countermovement Jump)** The countermovement jump was adopted to assess the impact of the strength intervention on the neuromuscular performance. The jumping performance was measured using a portable optical timing system (Optojump, Microgate, Bolzano, Italy). For that purpose, jumping performance was measured after the warm-up (MD-4, Baseline I, MD-3, baseline II), following the strength intervention (pre-strength, Post-M1; pos-strength, Post-M2) and in the end of the soccer specific session (pre-strength, Post-M2; pos-strength, Post-M1). Players were instructed to start from a standing upright position, following by a squat down until bending the knees to a 90 degree, to further immediately jump as higher as possible with the hands on the hips [8]. On each testing period (MD-4 testing days, n = 6 jumps per athlete; MD-3 testing days, n = 4 jumps per athlete), participants were asked to perform two maximal jumps with a 30-s rest interval, and the best trial was kept for analysis to minimize the impact of any suboptimal attempts and to provide a more accurate representation of the participants' true capacity.

**Linear Sprint Tests (10 and 30 m Sprint)** Similar to the counter-movement jump, the sprinting performance was measured after the warm-up, following the strength intervention and in the end of the soccer specific session (see Fig. 1). The sprints were measured using three pairs of photoelectric cells (Witty, Microgate, Bolzano, Italy) positioned at 0 m, 10 m, and 30 m, to allow to capture both sprints in only one trial, and positioned at a height of 1 m from the ground. To assess the sprint, players were instructed to start from an upright standing position with the front foot placed at −0.5 m before the first timing gate on the respective marker [2]. On each testing period (MD-4 testing days, n = 6 sprints per athlete; MD-3 testing days, n = 4 sprints per athlete), participants were asked to perform one maximal sprint, and the time for both 10 m and 30 m was kept for analysis. A single repetition was performed to minimize the potential influence of the test on the overall protocol outcomes. A 2-min recovery interval was provided between the jumping and sprinting performance tests.

**External Load** Players' external load during the MD-4 and MD-3 sessions were collected using 10 Hz Global Positioning System (GPS) units (10 Hz, Accelerometer 1 kHz, FieldWiz, Paudex, Switzerland), which have been shown to possess good level of accuracy to measure movements and displacements of players' during team sports activities [59]. To guarantee a higher data reliability, across the 4 weeks of data collection, the players always used the same unit, which was placed on a specific vest on the upper back of the player. The following variables were used to inspect the players' external load in both MD-4 and MD-3 sessions [30, 32]: (i) total distance covered; (ii) distance covered while walking (0.0–3.5 km/h); (iii) distance covered while jogging (3.6–14.3 km/h); (iv) distance covered while running (14.4 – 19.8 km/h); (v) distance covered while sprinting (> 19.9 km/h); (vi) number of high accelerations (> 3 m/s); (vii) number of high decelerations (> 3 m/s). These variables offer a clearer understanding of the overall physical demands of the training sessions.

### Statistical Analysis

Individual and mean changes from the Baseline I to Post-M1, Post-M2 and from Baseline II to Post-M3 for both conditions (pre-strength and post-strength) were graphically represented and the variation from those moments were expressed in percentage variation (mean ± SD). In addition, both intra-day (i.e., between-players) and inter-day (i.e., within players) variability was measured as typical error and expressed as coefficient of variation, CV (%).

All data were inspected for outliers and assumptions of normality. Further, a repeated measures ANOVA was used to compare each moment (baseline I, Baseline II, Post-M1, Post-M2, Post-M3) in accordance with the strength intervention period (pre-strength and post-strength). Pairwise differences were assessed using the Bonferroni post-hoc. The Jamovi Project software (Computer Software Version 2.3.21.0, 2023) was used to develop the statistical analysis, using $P < 0.05$ as statistical significance.

Complementarily, to realize the magnitude effects between testing periods (i.e., baseline I, Post-M1, Post-M2, baseline II and Post-M3) and intervention period (pre-strength and post-strength) it was used a specific spreadsheet. These effects were estimated in raw units based on log-transformation and uncertainty in the estimate was expressed as 95% confidence limits [34]. In addition, (Cohen's *d*) mean differences and respective 95% confidence intervals were processed using the following limits: 0.2, trivial; 0.6, small; 1.2, moderate; 2.0, large; and 0.20, very large [17].

## Results

### Internal and External Load Effects on Training Days

The results from the players' internal load measured with the Hooper Index and Rate of Perceived exertion and the external load based on players' distance covered at different speed zones and accelerations and decelerations (> 3 m/s) are reported on Table 1. As regard to internal load, significant differences were reported between the MD-4 and MD-3 of the post-strength ($F = 3.27$, $P = 0.03$), with higher values of muscle soreness being reported before MD-3 session. Differences between the MD-4 and MD-3 were also identified in the PRE-STRENGTH condition, with higher values registered before the MD-3 session ($F = 1.69$, $P = 0.008$).

From the external load perspective, significant effects were identified for total distance covered ($F = 21.1$, $P < 0.001$), jogging distance ($F = 25.6$, $P < 0.001$), running distance ($F = 15.9$, $P < 0.001$), and number of high accelerations (> 3 m/s, $F = 3.29$, $P = 0.032$). Accordingly, higher total distance covered (m) were identified in both MD-3 sessions than MD-4 sessions (pre-strength, $P < 0.001$; post-strength, $P < 0.001$). Similarly, higher jogging distance were identified in both MD-3 sessions than MD-4 sessions (pre-strength, $P < 0.001$; post-strength, $P < 0.001$), as well as higher running distance (pre-strength, $P = 0.002$; post-strength, $P < 0.001$). In relation to high accelerations, decrements were identified in the MD-3 compared to the MD-4 of the post-strength (> 3 m/s, $P = 0.004$).

The intra-day %CV (between-players) revealed a 7.8% ± 1.2%, 8.8% ± 1.2%, 9.6% ± 0.8%, 10.7% ± 2.6%, 9.4% ± 1.4% in the players' jumping performance (cms) for the baseline I, Post-M1, Post-M2, baseline II and Post-M3, respectively.

As for the 10 m sprint (s), it was found a variation (%CV) of 6.4% ± 3%, 5% ± 0.2%, 6.6% ± 0.6%, 4.4% ± 0.7%, 5.4% ± 0.1% for the baseline I, Post-M1, Post-M2, baseline II and Post-M3, respectively, while a variation of 4.3% ± 1.8%, 3.7% ± 0, 4.8% ± 0.4%, 3.6% ± 0.7%, 4.2% ± 0.3% for the baseline I, Post-M1, Post-M2, baseline II and Post-M3 in the 30 m sprint (s).

In contrast, the inter-day (within-players) for the jumping performance (cms) revealed variations of 1.5% ± 2.6%, 2.7% ± 2.8%, 2% ± 3.2%, 2.5% ± 3.4%, and 3.0% ± 3.1% for the Baseline I, Post-M1, Post-M2, Baseline II and Post-M3, while of 0.1% ± 0.1% in all moments of the 10 m sprinting performance, while of 0.1% ± 0.2% in all moments during the 30 m sprinting performance (Fig. 2).

The effects of the strength training intervention on the physical performance according to the time-period of implementation (pre-strength vs. post-strength) on the different assessment periods (baseline I, Post-M1, Post-M2, baseline

**Table 1** Descriptive and inferential statistics from the internal and external load according to the training day (MD-4 or MD-3) and intervention (pre-strength or post-strength)

| Variables | Pre-strength | | | Post-strength | | | F | MD-4 (PRE vs. POST) | MD-3 (PRE vs. POST) |
|---|---|---|---|---|---|---|---|---|---|
| | MD-4 (M ± SD) | MD-3 (M ± SD) | P | MD-4 (M ± SD) | MD-3 (M ± SD) | P | | P | P |
| Perceptual | | | | | | | | | |
| Sleep (scores) | 3.13 ± 0.99 | 3.58 ± 1.44 | 0.250 | 2.95 ± 1.32 | 3.0 ± 1.03 | 0.250 | 2.34 | 0.250 | 0.06 |
| Stress (scores) | 3.33 ± 1.09 | 3.33 ± 1.23 | 0.250 | 2.95 ± 0.94 | 3.0 ± 0.97 | 0.250 | 0.24 | 0.250 | 0.250 |
| Fatigue (scores) | 3.67 ± 0.76 | 3.42 ± 1 | 0.107 | 3.35 ± 1.09 | 3.5 ± 1.21 | 0.250 | 1.10 | 0.250 | 0.250 |
| Muscle soreness (scores) | 3.63 ± 0.77 | 3.75 ± 1.06 | 0.163 | 3.25 ± 1.02 | 3.81 ± 0.91 | **0.03** | 3.27 | 0.250 | 0.250 |
| RPE (scores) | 5.56 ± 1.15 | 5.27 ± 1.68 | 0.06 | 5.64 ± 1.15 | 5.33 ± 1.03 | 0.250 | 1.69 | 0.268 | 0.250 |
| External load | | | | | | | | | |
| Total distance covered (m) | 4058.84 ± 519.52 | 5095.05 ± 597.53 | **< 0.001** | 4496.22 ± 500.38 | 5038.78 ± 515.63 | **< 0.001** | 21.1 | 0.250 | 0.08 |
| Walking distance (m) | 856.06 ± 227.18 | 787.29 ± 246.19 | 0.121 | 901.19 ± 265.5 | 793.54 ± 177.07 | 0.06 | 1.45 | 0.250 | 0.250 |
| Jogging distance (m) | 2744.17 ± 449.55 | 3650.1 ± 499.52 | **< 0.001** | 3175.65 ± 347.99 | 3670.08 ± 387.95 | **< .001** | 25.6 | 0.250 | 0.250 |
| Running distance (m) | 283.19 ± 102.38 | 479.64 ± 215.89 | **0.002** | 271.15 ± 68.15 | 407.65 ± 129.4 | **< .001** | 15.9 | 0.250 | 0.10 |
| Sprinting distance (m) | 194.13 ± 64.92 | 178.02 ± 71.02 | 0.250 | 148.25 ± 45.8 | 167.51 ± 59.37 | 0.250 | 3.89 | 0.250 | 0.250 |
| Accelerations (> 3 m/s) | 20.83 ± 7.97 | 17.59 ± 6.69 | 0.250 | 26.65 ± 10.65 | 19.83 ± 8.36 | **0.04** | 3.29 | 0.123 | 0.250 |
| Decelerations (> 3 m/s) | 14.45 ± 10.01 | 14.97 ± 8.73 | 0.250 | 17 ± 10.06 | 15.87 ± 9.8 | 0.250 | 0.879 | 0.250 | 0.250 |

The bold values represent statistically significant effects between the conditions ($P < 0.05$)

II and Post-M3) are presented on Table 2 and Fig. 3. In general, statistically significant effects were only identified in the CMJ (cm, $F=5.21$, $P<0.001$) and 30 m sprint (s, $F=5.14$, $P<0.001$).

As regard to the within differences, the Post-M1 in the pre-strength showed lower values for the CMJ than baseline I ($-1.8\pm1.02$ cm, $P=0.02$, small effects) and Post-M2 ($2.0\pm0.82$ cm, $P=0.08$, small effects), while the Baseline II showed lower values than the Post-M3 ($3.32\pm1.72$ cm, $P=0.001$, moderate effects). In contrast, during the post-strength, higher values in the POST-M1 were identified when compared to baseline I ($1.26\pm0.62$ cm, $P=0.001$, small effects) and Post-M2 ($-2.0\pm0.78$ cm, $P<0.001$, small effects). As regard to the between comparisons, the Post-M1 of the POST-STRENGTH showed higher values for the CMJ than the Post-M1 of the pre-strength ($3.62\pm1.77$ cm, $P=0.001$, small effects).

From the 30 m sprint performance (s), the Post-M2 in the pre-strength showed decrements (i.e., higher time required to perform the 30 m) when compared to both Baseline I ($0.11\pm0.07$ s, $P=0.04$, small effects) and Post-M1 ($0.0\pm0.09$ s, $P=0.002$, small effects). As regard to the post-strength, the baseline II showed statistically significant better performance than baseline I ($0.0\pm0.08$ s, $P=0.03$, moderate effects).

The variation between time-periods (i.e., baseline I—Post M1, baseline I—Post M2, Post M1—Post M2, baseline I—baseline II and baseline II—Post-M3) between the training intervention (pre-strength vs. post-strength) are presented on Table 3 and Fig. 4. From the jumping performance it was found a higher variation from baseline I to Post-M1 (↑ higher for post-strength, $8.5\pm4.4$ cm, $P<0.001$, unclear effects) in the post-strength compared to the pre-strength, while in turn a higher variation from Post-M1 to Post-M2 (↑ higher for pre-strength, $-11.3\pm3.2$ cm, $P<0.001$, small effects) in the pre-strength compared to the post-strength.

From the 10 m sprint (s), the results revealed a higher variation from the baseline II to Post-M3 (↑ higher for pre-strength, $3.4\pm3.0$ s, $P=0.030$, moderate effects) during the pre-strength than in the post-strength.

As regard to the 30 m sprint performance (s), there was a higher variation from baseline I to baseline II (↑ higher for post-strength, $-3.4\pm2.8$ s, $P=0.020$, moderate effects) (Fig. 4).

## Discussion

This study aimed to explore the effects of including eccentric bodyweight exercises (NHE and SLD) before and after MD-4 SOT on players' perceived exertion, perceived fatigue, jumping and sprinting performances, and external load across two consecutive sessions (i.e., MD-4 and MD-3 sessions). This study showed that including ECC routines before or after SOT may affect in different ways the players' readiness and physical performance during subsequent

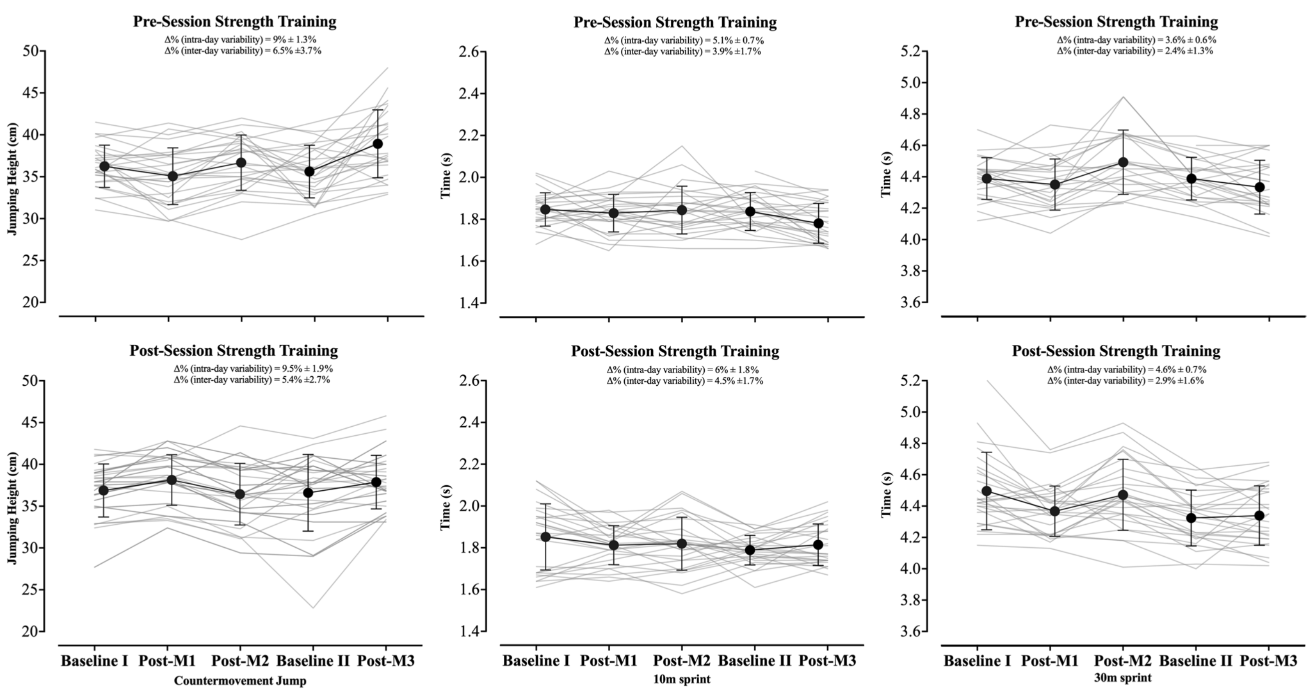


**Fig. 2** Individual and mean changes from baseline to Post-M1 and Post-M2 for counter movement jump (CMJ), 10 m sprint and 30 sprint test. Black lines represent the group mean with standard deviation while grey represents individual changes

**Table 2** Descriptive and inferential statistics from the differences between the training moments (baseline I, Post-M1, Post-M2, Baseline II, Post-M3) and strength intervention period (pre-strength vs. post-strength)

| Variables | Pre-strength | | | | | Post-strength | | | | | *F* | *P* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Baseline I (M ± SD) | Post-M1 (M ± SD) | Post-M2 (M ± SD) | Baseline II (M ± SD) | Post-M3 (M ± SD) | Baseline I (M ± SD) | Post-M1 (M ± SD) | Post-M2 (M ± SD) | Baseline II (M ± SD) | Post-M3(M ± SD) | | |
| CMJ (cm) | 36.26 ± 2.53 | 35.08 ± 3.39 | 36.7 ± 3.3 | 35.63 ± 3.14 | 38.95 ± 4.06 | 36.91 ± 3.17 | 38.16 ± 3.03 | 36.46 ± 3.69 | 36.63 ± 4.59 | 37.9 ± 3.21 | 5.21 | **< 0.001** [a,c,e,f,h,l,] |
| 10 m (s) | 1.85 ± 0.08 | 1.83 ± 0.09 | 1.85 ± 0.11 | 1.84 ± 0.09 | 1.78 ± 0.1 | 1.85 ± 0.16 | 1.81 ± 0.09 | 1.82 ± 0.13 | 1.79 ± 0.07 | 1.81 ± 0.1 | 1.88 | 0.06 |
| 30 m (s) | 4.39 ± 0.13 | 4.36 ± 0.16 | 4.5 ± 0.21 | 4.39 ± 0.14 | 4.34 ± 0.17 | 4.5 ± 0.25 | 4.37 ± 0.16 | 4.48 ± 0.23 | 4.33 ± 0.18 | 4.34 ± 0.19 | 5.14 | **< 0.001** [b,c,i,] |

Post-M1 (pre-training strength): post-strength; Post-M2 (pre-training strength): post-session; Post-M1 (post-training strength): post-session; Post-M2 (post-training strength): post-strength. The bold values mean significant differences. Letters represent differences according to the following conditions: a) baseline I vs. Post-M1 (pre-strength); b) baseline I vs. Post-M2 (pre-strength); c) Post-M1 vs. Post-M2 (pre-strength); d) baseline I vs. baseline II (pre-strength); e) baseline II vs. Post-M3 (post-strength); f) baseline I vs. Post-M1 (post-strength); g) baseline I vs. Post-M2 (post-strength); h) Post-M1 vs. Post-M2 (post-strength); i) baseline I vs. baseline II (post-strength); j) baseline II vs. Post-M3 (post-strength); k) baseline I (pre-strength vs. post-strength); l) Post-M1 (pre-strength vs. post-strength); m) Post-M2 (pre-strength vs. post-strength); n) baseline II (pre-strength vs. post-strength); o) Post-M3 (pre-strength vs. post-strength)

sessions. Generally, jumping and running capacities tend to decrease immediately after ECC when performed before SOT. However, while players are able to recover jumping capacity during training, running performance is impaired throughout the entire SOT. On the other hand, performing ECC after SOT may impact players' readiness and performance in the subsequent day (MD-3), with greater muscle soreness, lower number of high intensity acceleration actions and increased time in linear sprint.

## Strength before Soccer Training

When ECC was performed before SOT, both jumping and running capacities were impaired immediately after. However, while CMJ performance returned to baseline values after SOT, sprinting capacity was impaired. Given the importance of posterior chain eccentric training in optimizing soccer players' performance and reducing injury risk [53], the exercises proposed in present investigation were particularly focused on the eccentric action of the hamstrings. These exercises, such as the NHE and the SLD, are known to target posterior chain muscles and promote high levels of activity, particularly in the hamstrings [5, 51]. While some athletes may benefit from acute potentiation after these routines, others may be negatively affected by fatigue. For example, previous research with amateur soccer players showed that performing NHE before SOT resulted in significant eccentric hamstring strength decrements, particularly in elongated muscle lengths, that may persist throughout the training session [38]. These force impairments may result from overstretching and disrupted sarcomeres [47], leading to acute muscle soreness, particularly in players who are not accustomed to eccentric training [50]. Similarly, acute performance decrements were observed after performing flywheel eccentric half-squat with youth players with little experience in strength training [15]. In fact, balance between fatigue and potentiation seems to be more favorable to athletes with increased training experience and strength levels [60], since higher training status seems to be associated to better neuromuscular functioning of the hamstrings muscles, even in fatigued condition [25]. Under this scope, previous research found increases in jumping capacity 5 min after trained athletes performed 5 sets of 1 repetition of the back squat performed at 90% of one maximum repetition, while recreationally individuals showed an acute performance decline [14]. In soccer, a recent study also showed that players with experience in strength training may acutely improve running and jumping capacities after performing low-volume high-load deadlifts [1]. However, players that participated in the present investigation were from a regional-level and had no strength training experience, which may have exacerbated muscle fatigue in the moments following ECC intervention. Interestingly, while

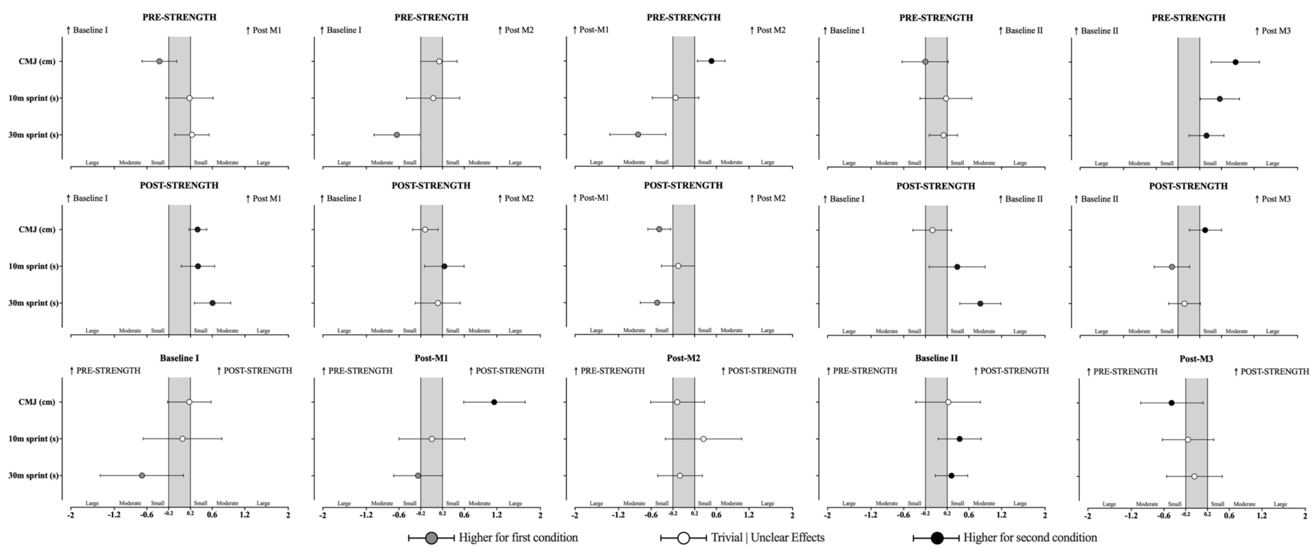


**Fig. 3** Cohen's *d* for within comparison of from the baseline to post-moments test protocols. Error bars indicate uncertainty in true mean changes with 95% confidence intervals. Grey color points indicate higher valuers for the first condition, while black for the second one. White-based color indicates unclear or trivial effects

jumping performance returned to baseline values after SOT, linear sprint was impaired throughout the entire session. As linear sprint elicits maximal eccentric activation of hamstrings muscles, particularly during the swing phase [52], fatigue resultant from the eccentric exercises focused on the posterior chain may have affected running performance at a greater extent and for a longer period. In fact, it was already reported that the eccentric load imposed by NHE may have a negative acute impact on sprint performance [56]. Additionally, the acute effects of eccentric exercise combined with the external load imposed by regular soccer training may have increased fatigue of posterior chain muscles [49] and consequently impaired running capacity. On the other hand, countermovement jump requires greater participation of muscles from anterior chain, such as quadriceps and vastus medialis [40], which means that vertical jump capacity may have been less affected by the NHE and SLD, two exercises predominately focused on hamstrings muscles. Even though players' CMJ values decreased immediately after the ECC, the soccer training time window allowed players to recover jumping performance at the end of the SOT.

### Strength after Soccer Training

In the POST-STRENGTH condition, jumping and running performances increased from the beginning to the end of the SOT. However, performing the eccentric exercises after the MD-4 SOT resulted in an acute decrease of both capacities. Even though these results were somehow expected, it was of greater interest to evaluate the players' physical readiness in the following day (MD-3). When comparing baseline values between MD-4 and MD-3, jumping capacity slightly decreased. Interestingly, CMJ values increased from the beginning to the end of MD-3 SOT. On the other hand, it was noticed that running capacity decreased at greater extent during MD-3 SOT when eccentric training was performed after MD-4 ST, particularly in 10 m sprint, which was not observed when eccentric exercises were performed before MD-4. Interestingly, external load profile during MD-3 also showed a lower number of high intensity accelerations when ECC was performed after MD-4.

Eccentric exercise is known to promote muscle damage, delayed onset of muscle soreness and force impairments in the following days, particularly in low level practitioners unaccustomed to eccentric training [10, 13]. It is also reported that eccentric stimulus resultant from NHE may diminish horizontal force production and maximum speed capacity up to 48 h after its application [4]. As previously mentioned, the present study showed decreased linear sprint capacity and lower number of high intensity accelerations 24 h after the ECC performed following MD-4 SOT. This may be related to the horizontal force impairments resultant from eccentric exercise performed under fatigue, particularly of hamstrings muscles that have a major role in producing horizontal force during sprint accelerations [46]. What the present investigation also adds is that players' muscle soreness was higher in MD-3 when ECC was performed after MD-4 training. Interestingly, muscle soreness peaks are commonly registered after 1–3 days after exercise and appear to be related to connective tissue damage and inflammation [20]. Thus, the results of the present study seem to show that eccentric stimulus after MD-4 training may

**Table 3** Analysis of coefficient of variation between the training moments (baseline I, Post-M1, Post-M2, Baseline II and Post-M3) and strength intervention period (pre-strength vs. post-strength)

| Variables | Pre-strength | | | | | Post-strength | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Post-M1 vs. Baseline I Δ (%) | Post-M2 vs. Baseline I Δ (%) | Post-M2 vs. Post-M1 Δ (%) | Baseline I vs. Baseline II Δ (%) | Baseline II vs. Post-M3 Δ (%) | Post-M1 vs. Baseline I Δ (%) | Post-M2 vs. Baseline I Δ (%) | Post-M2 vs. Post-M1 Δ (%) | Baseline I vs. Baseline II Δ (%) | Baseline II vs. Post-M3 Δ (%) |
| CMJ (cm) | ↓−3.23 ± 7.02 | ↑1.32 ± 7.25 | ↑4.84 ± 6.24 | ↓−1.52 ± 9.13 | ↑9.82 ± 12.73 | ↑3.57 ± 4.68 | ↓−1.15 ± 6.1 | ↓−4.51 ± 5.07 | ↓−0.75 ± 9.73 | ↑4.54 ± 11 |
| 10 m (s) | ↑−0.84 ± 5.5 | ↑-0.07 ± 6.17 | ↓0.89 ± 5.7 | ↑-0.77 ± 6.05 | ↑-2.98 ± 4.74 | ↑-1.79 ± 5.18 | ↑−1.44 ± 6.09 | ↓0.43 ± 5.24 | ↑−2.78 ± 8.71 | ↓1.49 ± 4.6 |
| 30 m (s) | ↑−0.86 ± 2.76 | ↓2.44 ± 3.59 | ↓3.32 ± 4.54 | ↑−0.49 ± 2.19 | ↑-1.23 ± 2.82 | ↑−2.73 ± 3.64 | ↑−0.42 ± 4.67 | ↓2.4 ± 3.74 | ↑−3.69 ± 4.1 | ↓0.41 ± 3.38 |

Post-M1 (pre-training strength): post-strength; Post-M2 (pre-training strength): post-session; Post-M1 (post-training strength): post-session; Post-M2 (post-training strength): post-strength

have resulted in increased muscle damage in MD-3 when compared to eccentric training performed before MD-4. Although literature is scarce about the effects of eccentric exercise performed under fatigue during the following days, it is known that concentric and eccentric torque output may be reduced after a single set of 5 repetitions of the NHE [42]. This higher perception of muscle soreness may have affected the players' predisposition during the SOT. In fact, it is currently accepted that players may voluntarily or involuntarily adjust their pace [48, 58] and external load output according to their pre-training wellness perception values [29]. This may mean that due to the increase muscle soreness, players may have adopted a slow pacing strategy as an intention to end the ST in a reasonable physical and psychological state. For example, it was previously shown that players decrease distance-related variables during small-sided games when receiving prior information of task duration (i.e., knowing or not that the small-sided game would last 12-min) [28], and this findings were consistent when considering longer-lasting tasks (20-min small-sided games) [27]. In addition, it was previously shown that the wellbeing scores would impact players' external load during training sessions [41], and consequently it may explain the lower values found in the MD-3 when the ECC is performed after the MD-4 SOT.

Even though performing eccentric exercises focused on hamstrings muscles before soccer training may impair eccentric strength and increase injury risk [38], coaches should also be aware that eccentric exercises performed after field training may increase players' muscle soreness and running performance in the next day training session. It is also important that coaches use adequate training methodologies that respect progressive load adjustments, players training level, and strength training experience [11]. The findings of this study are crucial for coaches and practitioners in integrating eccentric exercise routines with soccer training throughout the weekly cycle. By taking these implications into account, coaches can develop more effective and personalized training programs that boost performance while minimizing the risk of overtraining and injury.

This study was conducted with a relatively small sample size, focusing on one male amateur team. This means that findings might not be applicable to a wider population, including different age groups and various levels of playing experience. Thus, in the future studies may be expanded to include other training contexts.

## Conclusions

This study shows that the placement of eccentric routines within the weekly cycle may affect player's physical performance in different ways. Jumping and sprinting capacities tend to decrease immediately after eccentric routines when

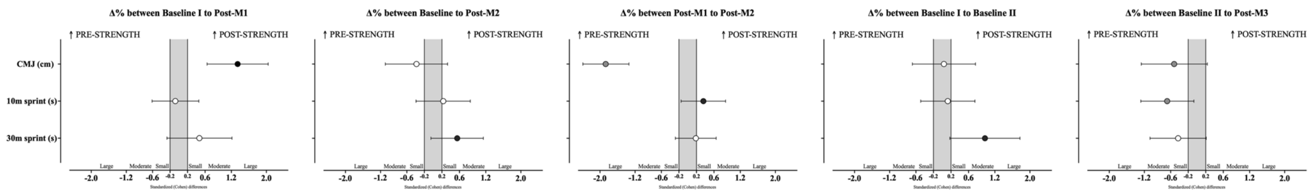


**Fig. 4** Cohen's *d* for within comparison of the % variation from the baseline to post-moments test protocols. Error bars indicate uncertainty in true mean changes with 95% confidence intervals. Grey color points indicate higher valuers for the first condition, while black for the second one. White-based color indicates unclear or trivial effects

performed before soccer training, however, while players are able to recover jumping capacity during training, sprinting performance is impaired in the following moments. On the other hand, performing eccentric routines after soccer training may impact players' readiness and physical performance in the subsequent day. Under this scope, coaches should consider players' eccentric training experience and strength levels, as less-experienced players may face potential negative impacts on performance in the following training session and even in the next day. These results reinforce the need for a strategic approach, balancing the potential benefits of eccentric training for performance optimization with the associated risks of increased muscle soreness and compromised physical capacity.

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**Data Availability** Data will be made available on reasonable request.

## Declarations

**Conflict of interest** The authors declare no conflict of interest.

**Ethical Approval** Considering that the data was obtained from regular monitoring of players' during competitive season, no ethical approval was required [61]. Nevertheless, approval from the club was obtained.

**Consent to Participate and to Publish** Written informed consent was obtained from all participants.



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