FACTORS AFFECTING PERFORMANCE AND RECOVERY IN TEAM SPORTS: A MULTIDIMENSIONAL PERSPECTIVE

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PUBLISHED IN: Frontiers in Physiology and Frontiers in Sports and Active Living

frontiers Research Topics

ISSN 1664-8714
ISBN 978-2-88974-922-5
DOI 10.3389/978-2-88974-922-5

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FACTORS AFFECTING PERFORMANCE AND RECOVERY IN TEAM SPORTS: A MULTIDIMENSIONAL PERSPECTIVE

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Citation: Trecroci, A., Formenti, D., Moran, J., Pedreschi, D., Rossi, A., eds. (2022). Factors Affecting Performance and Recovery in Team Sports: A Multidimensional Perspective. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88974-922-5

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frontiers in Physiology

EDITORIAL
published: 23 March 2022
doi: 10.3389/fphys.2022.877879

Editorial: Factors Affecting Performance and Recovery in Team Sports: A Multidimensional Perspective

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Keywords: recovery, fatigue, soccer, wellbeing, cognition, perceptual response, rugby, physical performance

OPEN ACCESS

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *17 February 2022*
Accepted: *28 February 2022*
Published: *23 March 2022*

Citation:
Trecroci A, Formenti D, Moran J, Pedreschi D and Rossi A (2022) Editorial: Factors Affecting Performance and Recovery in Team Sports: A Multidimensional Perspective. Front. Physiol. 13:877879. doi: 10.3389/fphys.2022.877879

Editorial on the Research Topic

Factors Affecting Performance and Recovery in Team Sports: A Multidimensional Perspective

In a team sports season, players likely experience congested fixture schedules, characterized by multiple games within a short timeframe (Carling et al., 2015). To face such a dense modern competitive schedule, players often undergo a high number of training sessions. The combination of multiple games and numerous training sessions within a short time could induce marked psychophysiological stress on an athlete, making recovery between competitive events a crucial element in the training process (Doeven et al., 2018; Silva et al., 2018). Indeed, congested fixture schedules typical of a team sports season can greatly affect the recovery process between the events, thus preventing athletes from attaining optimal performance levels (Trecroci et al., 2020b). A condition of prolonged fatigue might be reflected on the overall psychophysiological status of the athlete, causing neuromuscular and biochemical perturbations as well as physical and cognitive performance declines and technical skill impairments alongside an increased likelihood of injury occurrence (Dupont et al., 2010). As performance and recovery in team sports depend on several factors (physical, technical, physiological, psychological, cognitive, and morphological), advancing knowledge on this issue should be based on a multidimensional approach.

In this context, the present Research Topic extends knowledge on the factors affecting sport performance and recovery, emphasizing the use of novel strategies to alleviate the potential carryover effects of fatigue. This Research Topic addresses this theme with the contribution of ten original research articles and two reviews. Nine of the Research Articles focused on soccer, and one on rink hockey. One review focused on quantifying fatigue in rugby and one narrative review assessed the effect of cannabidiol supplementation for the enhancement of recovery. Moreover, four articles evaluated the change in performance relating to different training approaches such as situations external to sport (COVID-19 lockdown) and players' neuromuscular status, while eight articles investigated athletes' recovery status in relation to training methodologies and intensity, match and player characteristics and drug supplementation effects.

The detraining effect caused by the COVID-19 outbreak were investigated by Souza et al.. These authors evaluated the effect of the suspension of training on physical performance in soccer players competing in Spain's *La Liga*. In particular, the researchers compared players' running patterns before and after the lockdown period (8 weeks), reporting that the total running distance and the high intensity running performance of professional soccer teams was maintained after the resumption of the competition. Interestingly, the number of substitutions and match duration significantly increased after the lockdown period in comparison to the previous season.

Two articles described the effect of different training programmes on sport performance. Sariati et al. assessed the effect of a 6-week change of direction (CoD) training intervention on dynamic balance, horizontal jump, speed, and CoD with and without the ball in youth male soccer players with different levels of maturity status (measured relative to peak height velocity). The authors found that the CoD training program improved balance, horizontal jump, and CoD without the ball in male preadolescent and adolescent soccer players. Interestingly, a greater improvement was detected in the post-peak height velocity players compared to the pre-peak height velocity players. Accordingly, Sariati et al. suggested that peak height velocity should be considered when programming CoD training for soccer players. Alternatively, Koral et al. investigated the effect of three different preseason training programs (i.e., plyometric, sprint interval, and small-sided games training) on recreationally trained soccer players' physical performance (i.e., sprint ability, CoD, and maximal aerobic speed). In this study, the authors demonstrated that the most effective training programme was sprint interval training, followed by plyometric training, while the players that performed the small-side games training obtained the lowest performance improvement.

Pleša et al. investigated the association between bilateral deficit in the countermovement jump and sprint, bilateral and single-leg jump, and CoD in volleyball players. Small to moderate correlations of lower limb bilateral deficit with CoD, sprint ability, and jump performance were revealed, suggesting that these players' performance characteristics should be useful in programming the amount of training time that each volleyball player should dedicate to unilateral lower-limbs training.

Within the present Research Topic, particular emphasis was also given to the study of recovery, as part of the complex training process. Trecroci et al. sought to establish the impact of two different post-match training interventions on the recovery timeframe of both perceptual (muscle soreness) and biochemical parameters (e.g., creatine kinase) after a soccer match. In this study, the authors employed an active recovery (AR) or soccer-specific training sessions (SST) protocol on the second day after match performance. The researchers observed a higher restoration of muscle soreness and creatine kinase in AR compared with SST within 72 h post-match timeframe. This result provides additional and novel data that may aid practitioners' decision-making process when two consecutive games are played within a 3-day period. From a practical perspective, a low dose of high-intensity training (i.e., AR) performed 48 h after a game may be less detrimental *per se* for subsequent exercise performance.

Silva et al. analyzed variations over a 6-week period of short-duration maximal jumping performance in professional soccer players exposed to different accumulated training loads and matches. The authors found that match participation was the main factor influencing countermovement jump (CMJ) performance. Specifically, it was observed that the sum of weekly training session loads of high metabolic load distance, accelerations/decelerations and total distance covered by the players were the best predictors of the CMJ performance variation. This result provides coaches and practitioners with additional and extended knowledge on the importance of monitoring and managing GPS-based metrics linked to high-intensity demand activities (i.e., accelerations) weekly. This could help them to implement strategies to increase players' readiness to play.

Fernàndez et al. provided an integrative approach to external (based on a local positioning system) and internal load (perceived exertion) dynamics for monitoring fitness and fatigue status in elite rink hockey players during a standard periodised microcycle. The authors assessed the differences between training sessions and matches and the potential association between the external and internal load metrics (including distance covered, accelerations/decelerations, and high-speed skating). It was found that the training sessions 3 and 2 days prior to the nearest match demonstrated the greatest external and internal loads within the microcycle (also compared with the corresponding match loads) by exhibiting an inverted "U-shaped" load dynamic across the training period. Moreover, the authors reported moderate-to-large associations between volume-related variables (i.e., distance covered) and perceived exertion and low correlation between high-intensity-related (i.e., high-speed skating) variables and perceived exertion. This data facilitates a deeper understanding of the load distribution (internal and external loads during trainings and the weekly match) within a regular elite rink hockey team microcycle, providing practical guidelines for managing the weekly training programme.

The review by Naughton et al. dealt with post-match fatigue and recovery in rugby players competing in different events (i.e., rugby league, rugby union, and rugby sevens). The authors' intent was to better explore the recovery dynamics of neuromuscular (e.g., CMJ), biochemical (e.g., creatine kinase), and self-reported (e.g., muscle soreness) measures along with the association between match-related fatigue metrics due to collisions and high-intensity locomotor actions. Their findings revealed the presence of acute (up to 24 h post-match), residual (from 24 to 72 h) and persistent (beyond 72 h) "windows of fatigue" in which players experience a progressive change in performance, biochemical, and subjective recovery. Moreover, the authors highlighted how such recovery time course strongly relates to the frequency and intensity of collisions during a match. Altogether, these findings shed a light on the importance of quantifying post-match recovery in rugby under a multidimensional perspective to embrace the aggregate match-related carryover effects of collisions and high-intensity locomotor actions. Rugby players (regardless of competitive events played) would likely benefit from sufficient time to recover and return to their pre-match level of conditioning.

The narrative review by Rojas-Valverde focused on the potential role of cannabidiol (CBD) as an ergogenic aid to promote better recovery between efforts of training sessions and competitions. The recent removal of CBD from the list of prohibited substances from the World Anti-Doping Agency has increased both its use in sport professionals and the study of its properties. Although the paucity of literature on this issue, CBD was demonstrated to have properties to boost exercise recovery as an anti-inflammatory, neuroprotective, analgesic, anxiolytic, and pain reliever. This evidence supports the potentiality of CBD to be used as a strategy to improve the efficacy and efficiency of recovery processes during exercise and to offset sport-related fatigue. However, considering also the lack of studies in elite athletes, the review emphasized the call for additional studies to explore the underlying physiological mechanisms related to the use of CBD in the field of sports science.

One experimental study proposed a novel questionnaire to assess the types of recovery practices utilized in team sport (Querido et al.). Although practices to mitigate fatigue and improve recovery are widely known, few studies have investigated the types of recovery methods used in team sports and the underlying reasons for these choices by medical and technical staff. The authors of this study developed a valid and reliable online questionnaire to examine the practices adopted in the 72 h post-match period in soccer teams. The questionnaire was proposed in the Portuguese language but can be used as a basis for increasing the knowledge of the current recovery practices in team sports after appropriate validation in a specific language.

Ishida et al. investigated seasonal changes in training load, neuromuscular performance, subjective recovery, and stress status and examined the relationship between training load and neuromuscular changes in National Collegiate Athletic Association (NCAA) female soccer players. Long-term strategic training plans are necessary to maximize neuromuscular performance throughout the competitive season. The main findings of this study showed that neuromuscular performance gradually increased from pre-season to the competitive period. This was accompanied by a decrement in training load metrics. Significant negative correlations were observed for weekly total distance with CMJ height and peak power, while positive correlations were observed for player load and CMJ height. These findings highlight the importance of quantifying the summer, pre-season, and in-season training loads together with neuromuscular performance in female competitive soccer players.

The study by Bian et al. focused on a current hot topic within the sports-science literature (i.e., mental fatigue and physical performance). The negative effect of a mentally fatiguing task on physical performance in soccer is well-established (Coutinho et al., 2018; Smith et al., 2018; Trecroci et al., 2020a). Most studies investigating the effect of mental fatigue on physical performance utilized a computerized cognitive task for inducing mental fatigue, though this method is considered to have poor ecological validity. In their study, the authors proposed a novel motor task requiring soccer-specific skills (i.e., 20-min repeated interval Loughborough Soccer Passing Test, LSPT) for inducing mental fatigue in soccer as compared to computerized cognitive task. The 20-min repeated interval LSPT, as a soccer-specific motor task, induced subjective mental fatigue similar to that of the 20-min Stroop task. The mental fatigue induced by the repeated interval LSPT induced a similar detrimental effect as the 20-min Stroop task on cognitive and soccer-specific skill performance. These findings supported the use of the 20-min repeated interval LSPT as an ecological task to induce mental fatigue in soccer.

In conclusion, the articles published within this Research Topic contribute to advance knowledge for a better understanding of sport performance and recovery factors in team sports. Their findings highlight the complexity behind the interaction of training, competition, performance, and recovery. We hope that this Research Topic will stimulate further research in this area. Future studies should further advance knowledge on the topic of sports performance and recovery by striking a balance between the strict scientific rigor of the experimental setting (considering internal and external validity) and the high level of applicability required for team sports (helping practitioners to manage training load metrics) using a multidimensional approach. For example, within an ecological approach, further studies will have to focus on in-season training protocols to understand how different training strategies between multiple weekly matches may affect fatigue, by a combination of physiological and performance adaptations in the long term. Finally, we thank all the authors, reviewers and editors for their valuable contributions to this Research Topic.

AUTHOR CONTRIBUTIONS

AT, AR, and DF wrote the original draft of this editorial, while DP and JM reviewed and edited it. All authors have approved the final version of this editorial.

FUNDING

This work is supported by the European Community's H2020 Program under the Funding Scheme H2020-INFRAIA-2019-1 Research Infrastructures Grant Agreement 871042, www.sobigdata.eu, accessed on 2 November 2021, SoBigData++: European Integrated Infrastructure for Social Mining and Big Data Analytics. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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frontiers in Physiology

BRIEF RESEARCH REPORT
published: 26 April 2021
doi: 10.3389/fphys.2021.666593

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Running Patterns in *LaLiga* Before and After Suspension of the Competition Due to COVID-19

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In the first wave of the COVID-19 outbreak (spring 2020), the first division of professional soccer in Spain (*LaLiga*) was suspended for 12 weeks as part of the lockdown imposed by the Spanish health authorities. Professional soccer players were confined to home for 8 weeks and then a retraining period of 4 weeks was set before the first competitive match. When competition was resumed, professional soccer teams competed in a congested calendar (11 matchdays in 39 days) while some in-game regulations were altered (up to 5 substitutions, refreshment pauses). The current research presents an analysis of running patterns before suspension and after resumption of *LaLiga* to determine how the lockdown affected players' physical performance. To aid in this purpose, a pairwise comparison was performed of running patterns of the 2019–2020 vs. 2018–2019 season (i.e., control season). Using a two-way ANOVA (season x matchday), it was found that there was no main effect of the season on total running distance per match ($P = 0.288$) nor in the distances covered < 14.0 km/h ($P = 0.294$), at 21.0–23.9 km/h ($P = 0.266$), and at ≥ 24.0 km/h ($P = 0.112$). Only the distance at 14.0–20.9 km/h was affected by the season ($P = 0.019$) with a lower running distance on matchday 34 in the 2019–2020 vs. 2018–2019 season. The number of substitutions (from 2.9 to 4.5 substitutions per game; $P < 0.001$) and match duration (96 vs. 100 min; $P < 0.001$) significantly increased after resumption respect to the previous season. These data suggest that high-intensity running performance of professional soccer teams was maintained after the resumption of the competition while the alterations likely aided in the in-game regulations facilitated the maintenance of soccer physical performance.

Keywords: football, sports competition, elite athlete, professional athlete, sport performance

OPEN ACCESS

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *10 February 2021*
Accepted: *30 March 2021*
Published: *26 April 2021*

Citation:
Brito de Souza D, López-Del Campo R, Resta R, Moreno-Perez V and Del Coso J (2021) Running Patterns in LaLiga Before and After Suspension of the Competition Due to COVID-19. Front. Physiol. 12:666593. doi: 10.3389/fphys.2021.666593

INTRODUCTION

During the spring of 2020, the outbreak of the coronavirus disease (COVID-19) caused the suspension of sports competition worldwide, as their suspension was one of the several actions taken by most countries to reduce the spread of the virus. In most European countries, suspension of sports competition was accompanied by the lockdown of territories and home confinement.

In Spain, the first wave of COVID-19 impacted in March 2020 and national health authorities set a severe lockdown that entailed home confinement starting on March 14 (Castañeda-Babarro et al., 2020). At the beginning, the lockdown was set for a duration of two weeks and professional and elite athletes struggled to maintain their physical condition by training at home as it was believed that sports competitions would be resumed as soon as the lockdown finished (Sarto et al., 2020). However, at the end, home confinement lasted for 8 weeks and athletes had to perform multiple and innovative forms of home training in an attempt to mitigate the detraining effects of confinement on their physical conditioning.

In Spanish professional soccer, players tried to keep their training routines at their homes during home confinement, following individualized programs provided by the teams' strength and conditioning staff. The training programs mainly included strength-based activities with body loads, proprioception activities, exercise performed with low range displacements and some endurance-based exercises such as running on a treadmill or cycling on a stationary bike (Barca Innovation Hub, 2020). Despite the effort of the teams' staff, the inclusion of high-intensity running actions depended on the conditions of home confinement for each player. For this reason, the execution of soccer-specific displacements such as accelerations/decelerations, sprints, and changes of direction were difficult to perform at home for most players (Moreno-Pérez et al., 2020).

Due to the potential risks of infection and injury, most sports competition in Spain were not resumed after home confinement and they were concluded until the next season. However, the case of professional soccer was different to other sport competitions. Due to the economic revenues and the popularity of soccer, the suspension of the professional leagues was a matter of debate in health, social and sports forums. Most soccer governing bodies stood for the resumption of the competition to finish the championships after the lockdown was lifted, although there were calls to avoid an overly premature resumption of soccer competition in Spain and in other European countries (Corsini et al., 2020; Herrero-Gonzalez et al., 2020). In addition, there were statements that provided practical recommendations for the preparation of training sessions for professional soccerers when returning to competition after the lockdown (Bisciotti et al., 2020; Herrero-Gonzalez et al., 2020).

Spanish health and sports authorities set specific guidelines for the resumption of a few professional competitions (i.e., soccer, basketball). The guidelines for professional competition resumption were established keeping in mind athletes' health status after the confinement, the reduction of the likelihood of COVID-19 infection during training and competition and the development of strategies for injury prevention (Herrero-Gonzalez et al., 2020). In fact, recent data suggest that professional soccer training and competition could have been carried out safely after the first wave of the COVID-19 pandemic using strict hygiene measures, regular PCR testing (Buldú et al., 2020; Meyer et al., 2020) and systematic contact tracing following confirmed cases (Carmody et al., 2020).

Specifically, for the first division of professional soccer in Spain (*LaLiga*), a retraining period of 4 weeks was established after lockdown and then the competition was resumed on June 8 2020 and the 11 fixtures left to finish the championship were successfully completed without any infections. As new waves of COVID-19 are impacting again in Spain and in other European countries, the analysis of the data of the previous season may be very useful in the case of future lockdowns that entail sports competition suspension and posterior resumption. In this regard, the need of investigating the effect of lockdown on soccer performance has been suggested by analysing running activity patterns and game statistics in the matches played after soccer competition resumed (Souza et al., 2020). To this regard, although soccer is a complex team sport in which success is based on the interaction of multiple physical, technical and tactical capacities of players and of team squads (Sarmento et al., 2018), the analysis of running performance after the competition resumption may be useful to understand the outcomes of the 2019–2020 season of *LaLiga*, as running activities during the matches are related to end-season ranking in a national league (Longo et al., 2019). In addition, the analysis of running performance after the competition resumption in the 2019–2020 season may be helpful to set specific guidelines, based on precedents, that aid the return to play after lockdowns. Hence, the aim of this article is providing a comparative analysis of match running performance in teams competing in *LaLiga* before and after the lockdown due to COVID-19.

METHODS

Participants

The study sample was composed of 530 and 555 soccer players competing in *LaLiga* Santander for the 2018–2019 and 2019–2020 seasons, respectively. A total of 342 soccer players played on both seasons while the remaining 401 players only played on one of the two seasons under investigation. This sample corresponds to the entire population of professional soccer players that competed in *LaLiga* for these two seasons. The inclusion criteria were (a) being a soccer player competing in the first-division of soccer in Spain, (b) being professionally associated to one of the twenty teams competing in *LaLiga* and (c) playing at least one match in either the 2018–2019 and 2019–2020 seasons. In accordance with *La Liga*'s ethical guidelines, this investigation does not include information that identifies soccer players. The Institutional Review Board of the Camilo José Cela University approved this study, which is in accordance with the latest version of the Declaration of Helsinki.

Experimental Procedures

This study is a descriptive and comparative analysis of match running performance in all teams competing in *LaLiga* in the 2018–2019 and 2019–2020 seasons. To aid in determining the effect of lockdown in soccer running performance, a pairwise comparison of running patterns was performed between these two seasons. The 2018–2019 season was established as a "control" season while the 2019–2020 season was considered as the "experimental" season because entailed normal competition for 27 matches, a suspension for12 weeks and resumption to finish the 11 fixtures remaining.

The analysis includes the average running distance per game for each of the 38 matchdays that compose the first division of professional soccer in Spain, for a total of 560 matches analysed (i.e., 380 matches per season). Data were obtained from *LaLiga*, which authorised the use of the variables included in this investigation. Data were extracted by a valid and reliable multicamera tracking system and associated software (Mediacoach®, Spain) that measures players' running distance in total and at different speeds (i.e., below 14.0 km/h, between 14.0 and 20.9 km/h, between and 21.0 and 23.9 km/h and above 24.0 km/h). The number of running actions above 24.0 km/h was also obtained in each match to assess the number of sprints performed. Mediacoach® records the position of each player on the pitch at 25 Hz using a stereo multi-camera system composed of two multi-camera units placed at either side of the midfield line. Each multi-camera unit contains three cameras with a resolution of 1920 × 1080 pixels which are synchronised to provide a stitched panoramic picture (Del Coso et al., 2020). The panoramic picture is then employed to create the stereoscopic view that allows triangulating all the players on the field to assess their position and to calculate running speed during the match. In the case of a lack of location of a player due to occlusions by another player, an experienced operator manually corrected the position during measurement. The validity of Mediacoach® to assess running distance during soccer match play has been obtained through high agreement with the data obtained with Global Positioning System units (Felipe et al., 2019; Pons et al., 2019) and with data obtained from a reference camera system (i.e., VICON motion capture system (Linke et al., 2020)). Data on each variable was normalised as team's running distance per match to obtain easier-to-use information for coaches and physical conditioning staff (Brito Souza et al., 2020). Additionally, the number of substitutions per match and match duration were also extracted to assess the effect of the in-game regulations introduced after the resumption of the competition.

Statistical Analysis

Statistical analyses were carried out using the software IBM SPSS Statistics for Macintosh, Version 26.0 (IBM Corp., Armonk, NY, United States). Data were normally distributed in all variables as determined by the Shapiro-Wilk test. Additionally, the sphericity assumption was checked with Mauchly's test. If this assumption presented a probability of $P < 0.05$, the Greenhouse-Geisser correction was used. To identify the effects of the lockdown on match running performance variables, we used a two-way analysis of variance (ANOVA) with within-between comparisons (season × matchday), and an LSD post-hoc analysis in those variables with a significant F test. To specifically examine the effect of lockdown on the fixtures performed after the resumption of the soccer competition, a sub-analysis comparing the last 11 fixtures (from the fixture 28 to the fixture 38) of the 2018–2019 and 2019–2020 seasons was performed. For this sub-analysis, we used unpaired t tests while the effect size was also calculated by using Cohen's *d* units (Cohen, 1988). The significance level was set at $P < 0.050$.

RESULTS

The two-way ANOVA revealed that there was no main effect of the season or season × matchday interaction on total running distance per match, in the distances covered < 14.0 km/h, in the distance covered between 21.0 and 23.9 km/h, and in the distance covered at ≥ 24.0 km/h (**Figure 1**; see **Table 1** for F and *P* values). Likewise, there was no main effect of the season nor season × matchday interaction in the number of sprints performed at ≥ 24.0 km/h. However, there was a main effect of the season on the distance covered at 14.0–20.9 km/h ($P = 0.019$) with the post-hoc analysis revealing lower distances in the 2019–2020 season vs. 2018–2019 season for matchdays 32, 34, and 35 ($P < 0.050$). Additionally, the distance covered at 14.0–20.9 km/h was lower on matchdays 32, 34, 35, 36, 37, and 37 with respect to matchday 27 of the 2019–2020 season ($P < 0.050$).

The two-way ANOVA also revealed main effects of the season, matchday and an interaction between these two factors in the number of players' substitutions that the teams used per match (**Table 1**). Specifically, the number of substitutions was higher in all pairwise comparisons between the 2018–2019 vs. 2019–2020 season from matchday 28 to matchday 38 (**Figure 1**; $P < 0.050$). Furthermore, the number of substitutions was higher from matchday 28 to matchday 38 when compared to matchday 27 of the 2019–2020 ($P < 0.050$). There was also a main effect of the season on match duration (**Table 1**), indicating that match duration was higher from matchday 28 to matchday 38 in the 2019–2020 season with respect to the previous season ($P < 0.050$) while match duration was higher from matchday 28 to matchday 38 when compared to matchday 27 within the 2019–2020 season ($P < 0.05$).

In the sub-analysis of the last 11 matchdays of each season, total running distance and the distance at < 14.0 km/h were higher in the 2019–2020 season when compared to the 2018–2019 season ($P < 0.050$; **Table 2**). Additionally, the number of substitutions and match duration was higher the 2019–2020 season when compared to the 2018–2019 season ($P < 0.050$). On the contrary, the distance covered between 14.0 and 20.9 km/h was lower in the 2019–2020 season when compared to the 2018–2019 season ($P = 0.034$). There were no other differences between seasons in the remaining running performance variables in the last 11 matchdays of the seasons under investigations.

DISCUSSION

This analysis reveals that, despite the lockdown imposed by the Spanish health authorities during spring 2020 to control the first wave of the COVID-19 pandemic, running performance in the professional soccer teams of *LaLiga* was well preserved after the resumption of the competition, which took place after 12 weeks of competition suspension. This maintenance of overall running performance during the match was evident when comparing

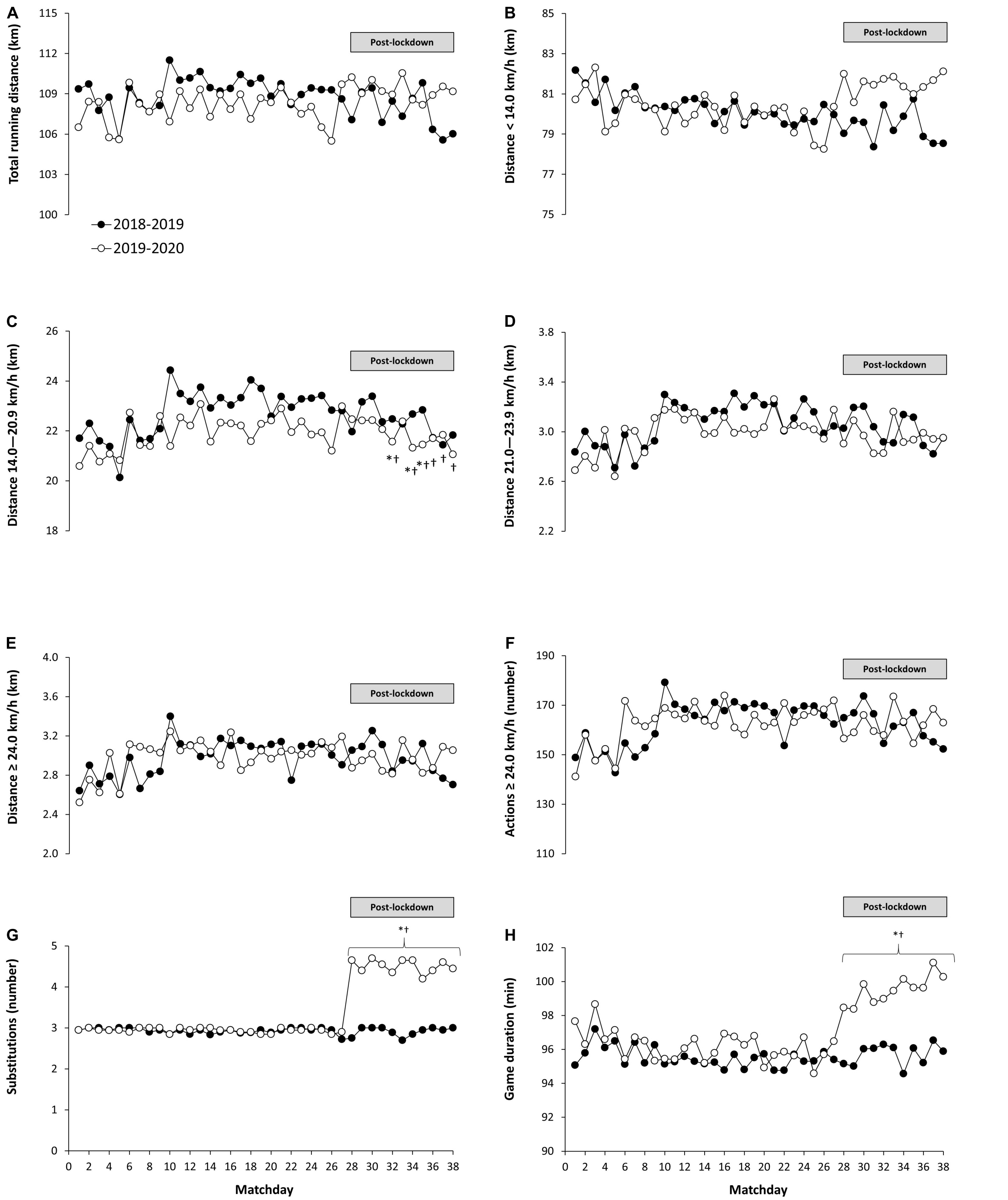

FIGURE 1 | Total running distance per match, distance at different speed thresholds, number of sprints, players' substitutions, and game duration in *LaLiga* in the 2018–2019 and 2019–2020 seasons. **(A)** Total running distance, **(B)** running distance covered at <14.0 km/h, **(C)** running distance covered between 14.0 and 20.9 km/h, **(D)** running distance covered between 21.0 and 23.9 km/h, **(E)** running distance covered at ≥24.0 km/h, **(F)** number of sprints covered at ≥24 km/h, **(G)** number of players' substitutions, **(H)** game duration. Each dot represents mean value for 20 teams on each matchday for each season (*) Different from the same matchday in the 2018–2019 season, $P < 0.05$. (†) Different from matchday 27 in the 2019–2020 season, $P < 0.05$. Note: In the 2019–2020 season, the competition was suspended after matchday 27 due to the COVID-19 pandemic. The competition was resumed after 12 weeks (8 weeks of lockdown and 4 weeks of retraining) to complete the 38 matchdays that comprised *LaLiga*.

TABLE 1 | Main effects (season × matchday) and interaction in running patterns of professional soccer teams in *LaLiga* when comparing the 2018–2019 and 2019–2020 seasons.

Variable	Season	Matchday	Interaction
Total running distance	F = 1.361 $P = 0.288$	F = 1.405 $P = 0.254$	F = 1.588 $P = 0.193$
Distance at <14.0 km/h	F = 1.321 $P = 0.294$	F = 0.751 $P = 0.415$	F = 0.893 $P = 0.433$
Distance at 14.0–20.9 km/h	F = 11.657 $P = 0.019$	F = 1.553 $P = 0.234$	F = 1.037 $P = 0.414$
Distance at 21.0–23.9 km/h	F = 1.564 $P = 0.266$	F = 2.079 $P = 0.128$	F = 1.588 $P = 0.193$
Distance at ≥24.0 km/h	F = 3.470 $P = 0.112$	F = 1.305 $P = 0.294$	F = 1.482 $P = 0.220$
Actions at ≥24.0 km/h	F = 2.077 $P = 0.209$	F = 0.981 $P = 0.436$	F = 1.151 $P = 0.361$
Number of substitutions	F = 308.197 $P < 0.001$	F = 19.603 $P < 0.001$	F = 22.890 $P < 0.001$
Match duration	F = 7.200 $P < 0.001$	F = 3.522 $P = 0.385$	F = 7.344 $P = 0.110$

In the 2019–2020 season, the competition was suspended at matchday 27 due to the COVID-19 pandemic. The competition was resumed after 12 weeks (8 weeks of lockdown and 4 weeks of retraining) to complete the 38 matchdays that comprised LaLiga.

TABLE 2 | Averaged running patterns of professional soccer teams in *LaLiga* in the last 11 fixtures of the 2018–2019 and 2019–2020 seasons.

Variable	2018–2019	2019–2020	P value	Effect size
Total running distance	107.7 ± 1.5	109.3 ± 0.7	0.015	1.10
Distance at <14.0 km/h	79.3 ± 0.8	81.5.3 ± 0.4	<0.001	2.75
Distance at 14.0–20.9 km/h	22.4 ± 0.6	21.9 ± 0.5	0.034	–0.81
Distance at 21.0–23.9 km/h	3.0 ± 0.1	3.0 ± 0.1	0.226	0.10
Distance at ≥24.0 km/h	3.0 ± 0.2	2.9 ± 0.1	0.759	–0.13
Actions at ≥24.0 km/h	162.1 ± 6.6	162.1 ± 5.6	0.994	0.00
Number of substitutions	2.9 ± 0.1	4.5 ± 0.2	<0.001	14.7
Match duration	95.7 ± 0.6	99.5 ± 0.8	<0.001	6.6

data of the season disrupted by the pandemic (2019–2020) to a control season (2018–2019), as running performance in all speed thresholds -except for some matchdays in the distance covered at between 14.0–20.9 km/h (**Figure 1C**) were maintained or even increased. The sub-analysis of the last 11 fixtures revealed that, both, the total running distance, and the distance covered at low running velocity (i.e., <14 km/h) were increased in the 2019–2020 season (**Table 2**) respect to the previous season. This increase in total running distance and in low-intensity running were likely facilitated by the longer match duration and the possibility of reaching up to five substitutions per match. Interestingly, the running distance at above 21 km/h, which represents the running actions more associated to soccer performance, particularly when in possession of the ball (Brito Souza et al., 2020) match, were well preserved in the 2019–2020 in comparison to the control season. It is probable that the maintenance of running distance at high speed and the number of sprints per match after the resumption of the competition was associated to the lower distance covered at 14.0–20.9 km/h (**Figure 1C** and **Table 2**). Although it remains as a speculation, the reduction of running activities of moderate intensity (i.e., 14.0–20.9 km/h) may represent an enhanced pacing strategy during matches to ultimately maintaining high-intensity running (i.e., > 21 km/h) despite a potential lower physical condition due to home confinement and the congested calendar. Collectively, all this information suggests that high-intensity running performance of professional soccer teams in *LaLiga,* was maintained after the resumption of the competition in the 2019–2020 seasons despite the competition was suspended for 14 weeks, including 8 weeks of severe home confinement.

These outcomes of the current investigation were likely assisted by management and regulations that Spanish health and soccer authorities established for professional soccer after the lockdown. In fact, it was predicted that, when resuming soccer competition after the lockdown, professional players of *LaLiga* would experience physical challenges similar to the ones they usually undergo during the first official matches of the season (i.e., a progressive increase in running performance during the first official matches (Souza et al., 2020)) because the lockdown was long enough to expect detraining effects (Pereira et al., 2020). This scenario was predicted with the data at that time which indicated muscle weakness induced by the lockdown (Moreno-Pérez et al., 2020) despite staff and soccer players trying to maintain their soccer-specific physical condition by training at home. However, this potential scenario did not materialise because the Spanish soccer authorities ensured players' health and safety and established regulations that avoided excessive fatigue while aiding soccer performance (Herrero-Gonzalez et al., 2020).

First, a retraining period of at least 4 weeks was set from the end of home confinement to the first competitive match. In this time, professional teams prepared their return to play following the recommendations of the Spanish Sports Council, in agreement with the Royal Spanish Soccer Federation (RSFF) and *LaLiga*, which established regulations to allow individual-only exercise routines for the first week of retraining with a progressive inclusion of small-group exercises until completing team trainings and 11-per side match simulation routines in the last weeks of the retraining period. Second, a minimum period of 72 h was set between matches as lower between-game recovery periods may entail accumulated fatigue and stress (Mohr et al., 2016) and could potentially lead to higher injury incidence (Bengtsson et al., 2014). Interestingly, the running patterns after the lockdown were preserved despite the teams completing the 11 matchdays remaining to finish the 2019–2020 season in ∼39 days (i.e., one game every 3.5 days). Of note, the previous year, the last 11 matchdays were completed in 63 days (i.e., one game every 5.7 days).

In the opinion of these authors, the specific modifications of the in-game regulations allowed after the lockdown were also key to maintaining players' physical running patterns (especially those above 21 km/h) and hence, the integrity of the competition. The RSFF and *LaLiga* agreed to permit two extra players' substitutions (for a total of up to 5 substitutions per match) although teams had to request substitutions in only three turns.

The current data indicate that most teams used this in-game allowance as the mean number of substitutions in the last 11 fixtures of the 2018–2019 season was 2.9 substitutions per game and it reached 4.5 substitutions per game in the 2019–2020 season (**Table 2**). Habitually, substitutes cover greater running distances than players who complete the entire match (Bradley et al., 2014) which points toward a favourable outcome of the allowance of up to 5 substitutions to preserve running performance after the lockdown. In this regard, some authors have recently proposed keeping the increase in substitutions from three to up to five permanently, with the aim of mitigating overall soccer physical demands (Mota et al., 2020). Interestingly, the time chosen for the first substitution did not vary after the lockdown (58 ± 3 min in 2018–2019 and 57 ± 2 min in 2019–2020 for the las 11 matchdays) and the time played by substitutes was similar (25 ± 2 min in 2018–2019 and 26 ± 1 min in 2019–2020 for the las 11 matchdays) suggesting that team managers do not anticipate substitutions despite possessing two more substitutions than before.

Additionally, a mandatory use of refreshment pauses at minute 30 and 75 of each match was established to allow enhanced in-game recovery as the game was stopped for ∼2 min in each half. As a result, game duration increased from 96 min in the last 11 fixtures of the 2018–2019 season to 100 min for the same period of the 2019–2020 season (**Table 1**). This likely produced that total running distance and distance at < 14 km/h were higher in the 2019–2020 vs 2018–2019 season (**Table 2**), as players usually moved at a low intensity running to the sideline for refreshment. To compensate for the time used for these pauses, referees increased game duration in each half as reflected in the current investigation, but the effective time of play was probably conserved. To date, there is no data to determine how effective these refreshment pauses are to help players' for in-game recovery, but the maintenance of the distance run at ≥ 21 km/h and the similar number of actions above 24 km/h in the post-lockdown period suggests that these drink breaks were be helpful to maintain running performance despite the congested calendar of the last 11 fixtures of the 2019–2020 season.

The current analysis describes an unusual situation produced by a virus pandemic and provides data on how health and soccer governing bodies were right about the proposition of new in-game regulations and by setting an appropriate time for retraining phase after home confinement. However, the analysis presents some limitations. First, the training routines performed at home during confinement and during the retraining period of 4 weeks were different between players and between teams. With the current data, we are unable to determine what teams selected the most optimal retraining strategies to maintain running performance after the resumption of competition. Additionally, the current analysis does not establish if those soccer teams that used a higher number of substitutions per game -up to five- were more able to maintain running performance after the resumption of competition. Last, the current analysis does not contain information about players' internal load during the matches or an evaluation of wellness before the matches. This information could have been useful to determine if players felt more fatigue before matches due to the congested calendar set for the resumption of the competition or if they presented a higher internal load in comparison to the 2018–2019 season. Despite these limitations, the authors of this brief report honestly believe that the information provided here can be useful for coaches and strength and conditioning staff to understand how running performance during soccer competition can be maintained after a detraining period induced by home confinement or other analogue measures.

In summary, running patterns in professional soccer teams competing in 2019–2020 *LaLiga* were maintained when the competition was resumed after lockdown due to the first wave of COVID-19, especially the distance covered at > 21 km/h. The 11 matchdays left to finish the championship were played with ∼3.5 days of recovery between matches but establishing 4 weeks of retraining, the authorisation for up to 5 player's substitutions during each match, and the mandatory use of refreshment pauses likely aided maintaining match running performance, at least when compared to that of the previous season. As the new wave of the COVID-19 pandemic are hitting most countries worldwide, it is expected that some sports competitions will have to be suspended to reduce the spread of the SARS-CoV2. The current data may be useful for sport's governing bodies to value the use of unusual regulations to reduce the stress of sports, particularly in those circumstances where athletes have been confined to home or when the competition has been suspended for several weeks. As the duration of lockdown and sports competition interruption may be substantially different among countries, future investigations should determine the best guidelines for sports competition resumption after suspension due to COVID-19. These best guidelines should include information about the length of retraining and modulation of some in-game regulations.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author. LaLiga is the owner of these data and this institution should approve any use of the data for further investigations.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Camilo José Cela University Ethics Committee. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

All the authors have equally contributed to the conception and preparation of this investigation. All authors have read and approved the final version of the manuscript and agreed with the order of presentation of the authors.

FUNDING

DB Souza received a Pre-Doctoral studentship from the Camilo José Cela University to carry out this study.

ACKNOWLEDGMENTS

We want to thank Mediacoach (Spain) for providing the data necessary to complete this work.

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Conflict of Interest: RL-D and RR were LaLiga employees during the preparation of this work.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Physiology

ORIGINAL RESEARCH
published: 24 May 2021
doi: 10.3389/fphys.2021.668437

Improvement of Physical Performance Following a 6 Week Change-of-Direction Training Program in Elite Youth Soccer Players of Different Maturity Levels

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Edited by:
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Reviewed by:
Ben Drury, Hartpury University, United Kingdom
Alessio Rossi, University of Pisa, Italy

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *16 February 2021*
Accepted: *16 April 2021*
Published: *24 May 2021*

Citation:
Sariati D, Hammami R, Zouhal H, Clark CCT, Nebigh A, Chtara M, Chortane SG, Hackney AC, Souissi N, Granacher U and Ounis OB (2021) Improvement of Physical Performance Following a 6 Week Change-of-Direction Training Program in Elite Youth Soccer Players of Different Maturity Levels. Front. Physiol. 12:668437. doi: 10.3389/fphys.2021.668437

Background: Change-of-direction (CoD) is a necessary physical ability of a field sport and may vary in youth players according to their maturation status.

Objectives: The aim of this study is: to compare the effectiveness of a 6-week CoD training intervention on dynamic balance (CS-YBT), horizontal jump (5JT), speed (10 and 30-m linear sprint times), CoD with (15 m-CoD + B) and without (15 m-CoD) the ball, in youth male soccer players at different levels of maturity [pre- and post-peak height velocity (PHV)].

Materials and Methods: Thirty elite male youth soccer players aged 10–17 years from the Tunisian first division participated in this study. The players were divided into pre- (G1, *n* = 15) and post-PHV (G2, *n* = 15) groups. Both groups completed a similar 6-week training program with two sessions per week of four CoD exercises. All players completed the following tests before and after intervention: CS-YBT; 5 JT; 10, 30, and 15 m-CoD; and 15 m-CoD + B, and data were analyzed using ANCOVA.

Results: All 30 players completed the study according to the study design and methodology. Adherence rate was 100% across all groups, and no training or test-related injuries were reported. Pre-PHV and post-PHV groups showed significant amelioration post-intervention for all dependent variables (after test > before test; $p < 0.01$, $d = 0.09$–1.51). ANOVA revealed a significant group × time interaction only for CS-YBT ($F = 4.45$; $p < 0.04$; $\eta^2 = 0.14$), 5JT ($F = 6.39$; $p < 0.02$; $\eta^2 = 0.18$), and 15 m-CoD ($F = 7.88$; $p < 0.01$; $\eta^2 = 0.22$). CS-YBT, 5JT, and 15 m-CoD improved significantly in the post-PHV group (+ 4.56%, effect size = 1.51; + 4.51%, effect size = 1.05; and -3.08%, effect size = 0.51, respectively), more than the pre-PHV group (+ 2.77%, effect size = 0.85; + 2.91%, effect size = 0.54; and -1.56%, effect size = 0.20, respectively).

Conclusion: The CoD training program improved balance, horizontal jump, and CoD without the ball in male preadolescent and adolescent soccer players, and this improvement was greater in the post-PHV players. The maturity status of the athletes should be considered when programming CoD training for soccer players.

Keywords: youth soccer, peak height velocity, change of direction speed, training adaptation, football

INTRODUCTION

Change-of-direction (CoD) is a necessary physical ability of a field sport athlete (Lloyd et al., 2013; Sattler et al., 2015; Hammami et al., 2018). This is due to the inherent design of field-based team sports (i.e., soccer, handball, basketball, and lacrosse), which places great emphasis on the ability of the athlete to run quickly and change directions during a game (Sekulic et al., 2017). Despite the significance of CoD for sports performance, it has neither been a prominent factor in the long-term athlete development of athletic training programs nor well studied in research (Lloyd et al., 2015). Lloyd et al. (2015), in their recent review studying the effects of growth, maturation, and training on CoD in a safe and effective manner, showed that applying an optimal CoD training stimulus for the duration of athlete development is crucial for effective programming and improving CoD athletic performance in youth.

There is a lack of research in the pediatric athletic population, pertaining to the determinants of CoD performances in prepubertal and early pubertal athletes, while the recent Youth Physical Development (YPD) models (Lloyd et al., 2013; Granacher et al., 2016) accentuated the need for a structured and logical approach to developing different types of CoD during childhood and adolescence. In this context, previous cross-sectional studies have examined the interaction between maturation and CoD development in both pre-peak height velocity (PHV) (Hammami et al., 2017; Negra et al., 2017) and post-PHV handball players (Hammami et al., 2018). Accordingly, Hammami et al. (2018) indicated a stronger association between conditioning abilities (i.e., jumping and sprinting) and CoD in early pubescent handball players of advanced maturity status (i.e., post-PHV players). These authors reinforce the need for differential strength and conditioning programs aimed at improving the CoD of young athletes who differ in maturity status. While there is ample evidence on the CoD/strength-and-power relationship in youth, less is known regarding the effects of CoD training on particular measures of physical fitness with respect to maturation. Chaalali et al. (2016) demonstrated that elite young male soccer players' physical performances can be significantly and specifically improved by either plyometrics or CoD or repeated sprint ability (RSA) training over short-term, in-season, training. In contrast, Padrón-Cabo et al. (2020) showed that coordination training with an agility ladder does not seem to be effective in improving physical fitness (i.e., 10-m sprint, 20-m sprint, dribbling speed test, and agility test) or dribbling (slalom dribbling test). Consequently, the purpose of the present study was to examine the effects of 6-week pre-season CoD training program on dynamic balance, horizontal jump (5 JT), speed (10- and 30-m linear sprint times), and CoD with and without the ball (15 m-CoD + B and 15 m-CoD tests, respectively), in male soccer players at different maturity statuses (pre- and post-PHV).

Concordant with earlier cross-sectional (Hammami et al., 2018) and longitudinal (Zemkova and Hamar, 2010; Asadi et al., 2017) investigations, we hypothesized that the more mature players would respond more favorably to CoD training.

MATERIALS AND METHODS

Participants

Thirty young male soccer players (age: from 10 to 17 years) participated in the study (see **Table 1**). The players volunteered for random assignment to either CoD training program in both pre-PHV (n = 15) and post-PHV (n = 15) groups. Afterward, biological maturity was evaluated, non-invasively, by incorporating measures of chronological age and body height into a regression equation to subsequently predict biological age from PHV (Moore et al., 2015). The equation has previously been validated for boys and presents standard error of estimate reported as 0.542 years (Moore et al., 2015). By this equation, all players were classified as pre- or post-PHV, respectively. All participants were free from lower-limb musculoskeletal injuries, physically active, and participated regularly in soccer training. All participating players performed systematic soccer practice in the first division of the Tunisian national soccer league for 3–7 years. The players exercised on average five times per week with each session lasting ∼90 min and one match played during the weekend. Players were not undertaking any additional training other than the team soccer training.

TABLE 1 | Design of the training program for both pre- and post-PHV soccer players.

CoD drills	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Exercise 1	1 × 4	2 × 5	2 × 6	2 × 7	1 × 5	3 × 6
Exercise 2	1 × 4	2 × 5	2 × 6	2 × 7	1 × 5	3 × 6
Exercise 3	1 × 4	2 × 5	2 × 6	2 × 7	1 × 5	3 × 6
Exercise 4	1 × 4	2 × 5	2 × 6	2 × 7	1 × 5	3 × 6

Set × repetition; example, (1 × 4) means that participants had to perform one set with four repetitions.

Before participation in this study, the participants were given a letter that included written information about the study and a request for consent from the parents to allow their children to participate in this study. Legal representatives and players provided informed consent after a thorough explanation of the objectives and scope of this project, the procedures, risks, and benefits of the study. This study was conducted according to the latest version of the Declaration of Helsinki, and the protocol was fully approved by the Local Ethics Committee of the National Centre of Medicine and Science of Sports of Tunis (CNMSS-LR09SEP01) before the commencement of the assessments.

Players' height and body mass were measured using a wall-mounted stadiometer and electronic scale, respectively. Body mass index (BMI) was calculated as mass/height squared (kg/m^2). Two skinfold thicknesses (triceps and sub-scapular) were measured, in triplicate, by the same trained investigator. Measurements were made on the right-hand side of the body using a Harpenden caliper (Baty International, West Sussex, England). Body fat percentage was estimated using the equations of Slaughter et al. (1988) for boys.

Sample Size

A minimum sample size of 30 was determined from an *a priori* statistical power analysis using G*Power (Version 3.1, University of Dusseldorf, Germany) (Faul et al., 2009). The power analysis was computed with an assumed power at 0.90, an alpha level of 0.01, and a small effect size of 0.38 for our primary outcome, 10-m sprint time (Hammami et al., 2016).

Procedures

All procedures were carried out during the first half of the competitive season. Before the commencement of the study, and prior to the initiation of baseline testing, all players completed a 2-week orientation period with three sessions per week to become familiar with the general environment, the applied physical fitness tests, and CoD exercises. A repeated-measures study design with pre–post tests and two experimental groups (i.e., pre- and post-PHV) was applied. Prior to testing, participants accomplished a standardized warm up consisting of low-intensity jogging, CoD, and balance and jumping exercises together with dynamic lower-limb stretching. Performance testing was conducted at the national team club "Ligue 1, Tunisia" pre–post the 6-week CoD training period and included the assessment of lower limb dynamic balance (CS-YBT), horizontal jump (5JT), CoD with (15 m-CoD + B) and without (15 m-CoD) the ball, and linear sprint performances (times over 10 and 30 m). The test sequence was randomized. Within 1 week, all tests were repeatedly performed and intra-class correlation coefficients (ICC), jointly with coefficients of variation (%CV), were assessed. Similar to other previously published training studies (McGawley and Andersson, 2013; Hammami et al., 2016), a true control group could not be included as the two experimental groups were national-level elite athletes and there were no comparable athletes available that would provide similar baseline values. Performance testing was initiated after a standardized 15-min warm-up program, including submaximal intensity running bouts; dynamic stretching; low-intensity forward, sideways, and backward running bouts; several accelerations; and vertical jumps. Intensity was progressively increased during the warm-up.

Dynamic Balance

Stability was assessed by the Y-Balance Test according to a previously described protocol (Hammami et al., 2017; Sariati et al., 2020), which has been shown to be reliable in both pre-PHV [ICC = 0.92 and standard error of mean (SEM) = 2.54] (Hammami et al., 2017) and post-PHV soccer players (ICC = 0.91, SEM = 0.49) (Sariati et al., 2020). For this purpose, players stood on the dominant leg, with the most distal aspect of their big toe on the center of the grid.

Thereafter, they were asked to reach the maximal distance in the anterior (A), postero-medial (PM), and postero-lateral (PL) directions, while maintaining their single-limb stance (Fusco et al., 2020). The maximal reached distance was measured with a measuring tape as the most distal point reached by the free limb. The trial was discarded and repeated if the player failed to maintain a unilateral stance, touched down with the reaching foot, or failed to return the reaching foot to the starting position. A composite score [CS-YBT (%)] was calculated and considered as the dependent variable using the following formula: CS-YBT (%) = [(maximum anterior reach distance + maximum posteromedial reach distance + maximum posterolateral reach distance)/(leg length × 3)] × 100.

Horizontal Jump

The five-jump test (5JT) was proposed to evaluate lower-limb horizontal jump in soccer players (Chamari et al., 2008). The testing protocol consists of five consecutive strides with joined feet position at the start and end of the jumps. From starting test, the participant was not approved to perform any back step with any foot; rather, he had to directly jump to the front with a leg of his choice. After the first four strides, i.e., alternating left and right feet for two times each, he had to perform the last stride and end the test again with joined feet. The test was performed again if the player fell back on completion of the last stride. Jumping performance was measured, in centimeters, with a tape measure from the front edge of the player's feet at the starting position to the rear edge of the feet at the final position. The strength specialist assessing the landing had to focus on the last stride of the player in order to exactly determine the last foot placement on the grass, as the players could not always stay on their feet on landing. The starting position was set on a fixed point (Chamari et al., 2008). Previous test reliability conducted with youth elite soccer players was considered high with an ICC = 0.91 and SEM = 0.30, respectively (Sariati et al., 2020).

Change of Direction With (15 m-CoD + B) and Without (15 m-CoD) the Ball

For the 15 m-CoD test (**Figure 1**), players departed running 3 m behind the initial set of gates.

Players performed 3 m of straight running, entered a 3-m slalom section marked by three aligned sticks (1.6 m of height) placed 1.5 m apart, and then cleared a 0.5-m hurdle placed 2

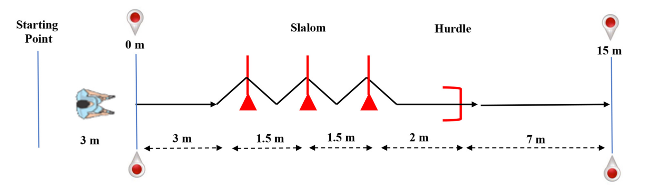


FIGURE 1 | A Schematic representation of the change-of-direction (CoD) test.

m beyond the third stick. Finally, players ran 7 m to break the second set of photocell gates, which stopped the timer (Mujika et al., 2009). An excellent test–retest reliability has been reported for the 15 m-CoD run test, with an ICC value of 0.93 (0.86, 0.97) (Chaalali et al., 2016).

The 15 m-CoD + B run test (**Figure 1**) is alike to the previously described 15 m-CoD shuttle run; however, players needed to dribble a ball while executing the test. Next, the slalom section of the test, the ball was kicked under the hurdle while the player cleared it. The participant then kicked the ball toward either of two small goals placed diagonally 7 m on the left and the right sides of the hurdle and ended with 7 m of straight sprint (Mujika et al., 2009). Previous test–retest reliability scores for the 15 m-CoD + B have been shown to be reliable in a similar pediatric population (ICC = 0.87, SEM = 0.04) (Chaalali et al., 2016). Players performed two trials of each test (3-min rest between trials), and the best performance was used for further analysis.

Linear Sprint Speed

Sprint performance was calculated using a stationary 10-m sprint and 30-m maximal speed test. The 10-m sprint comprised sprinting 10 m, as fast as possible. For all players, start stance was consistent. The 30-m maximal speed sprint comprised also sprinting 30 m as quick as possible from a moving start line. Participants were located 20 cm behind the starting line position and were instructed to run as fast as possible along the allocated distance. Sprint time was automatically noted using photocell gates (Brower Timing Systems, Salt Lake City, UT, United States; accuracy of 0.01 s) placed 0.4 m above the ground. Players performed two trials, with at least 5 min of rest between each trial, and the best trial was recorded for analysis. Previous test–retest reliability has demonstrated a high score in youth soccer players (Hammami et al., 2016; Makhlouf et al., 2018).

Change-of-Direction Training Program

All players trained five times per week (i.e., ∼90 min per session) with one match played during the weekend over the entire training period. Players of the two groups participated in a 6-week CoD training program, which was performed twice per week (see **Table 1**). Training volume was similar between groups during the study. Each training session endured 20–25 min and included four CoD exercises.

A recovery time of approximately 50 s was allowed between trials and 2–3 min between sets. The CoD training program involved a number of CoD actions usually used by players seeking to improve CoD performance (see **Figure 2**). All CoD sessions were supervised by certified strength and conditioning specialists. During all training sessions, the coaches provided verbal encouragements.

Statistical Analyses

Descriptive data were reported as means ± standard deviations (SD). Normal distribution of data was confirmed using the Shapiro–Wilk test, and baseline between-group differences were computed using independent samples *t*-tests. Subsequently, a 2 (group: pre-PHV and post-PHV) × 2 (test: pre and post) analysis of variance with repeated measures was used to identify the effects of the CoD training program on performance at different levels of maturity. Furthermore, group-specific repeated-measures analyses of variance (ANOVA) (time: before and after) were applied to evaluate within-group before-to-after performance changes. The effect size was calculated for all ANOVAs using partial eta-squared. The values of 0.01, 0.06, and 0.15 were considered as small, medium, and large cut-off points, respectively (Cohen, 1988). Effect sizes (ESs) were calculated for all paired comparisons and judged according to the following scale: ≤0.2, trivial; >0.2–0.6, small; >0.6–1.2, moderate; >1.2–2.0, large; and >2.0, very large (Hopkins et al., 2009). Test/retest reliability was assessed with Cronbach's model intraclass correlation coefficient (ICC) and coefficient of variation (CV). We considered an ICC over 0.90 as high, between 0.80 and 0.90 as moderate, and below 0.80 as low (Vincent, 1995), and CV values were considered acceptable if <10% (Cormack et al., 2008). For each ICC, the 95% confidence interval (CI) was calculated to take the sampling distribution into account. Statistical analyses were performed using SPSS (SPSS Inc., Chicago, IL, version. 20.0), and significance was accepted, *a priori*, at $p < 0.05$.

RESULTS

All players from pre-PHV and post-PHV groups completed the study according to the prescribed protocol. Participants attended all training sessions, and no training- or test-related injuries were reported. Reliability measures (ICC) for the assessed tests ranged from 0.90 to 0.96, while CV ranged from 1.27 to 3.98% (**Table 2**).

The analysis revealed a significant difference between groups for all anthropometric measurements, except BMI (p = 0.13). Accordingly, the post-PHV group was more advanced in age ($p = 0.001$; $d = 18.40$), maturity offset ($p = 0.001$; $d = 12.20$), height ($p = 0.001$; $d = 2.21$), and body mass ($p = 0.001$; $d = 1.82$) than the pre-PHV group. Inversely, the pre-PHV group was lower than the post-PHV in body fat (BF) ($p = 0.02$; $d = 0.93$) (**Table 3**).

The analyses indicated a significant main effect of time ($p < 0.001$; $\eta^2 = 0.53$–0.79) for all dependent variables. Both groups showed significant improvements, after intervention (after test > before test; $p < 0.01$) (**Table 4**). In addition, ANOVA revealed a significant group × time interaction only for CS-YBT ($F = 4.45$; $p < 0.04$; $\eta^2 = 0.14$), 5JT ($F = 6.39$; $p < 0.02$; $\eta^2 = 0.18$), and 15 m-CoD ($F = 7.88$; $p < 0.01$; $\eta^2 = 0.22$). CS-YBT, 5JT, and 15 m-CoD improved significantly in post-PHV to a greater extent

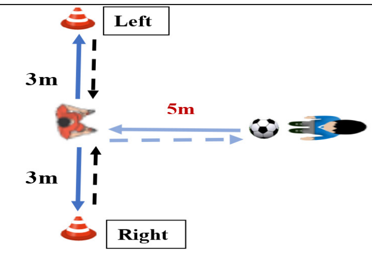
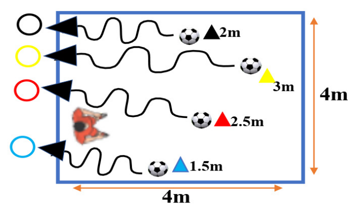
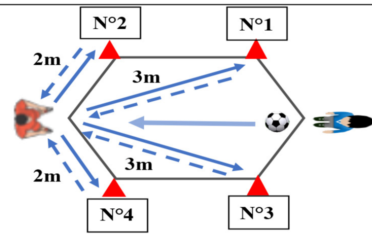
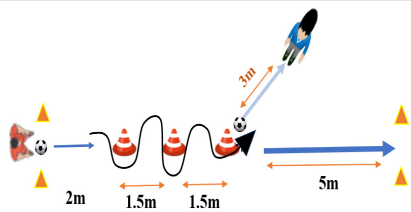
Exercise 1: Preplanned lateral shuttle run of 3-meters pre-established (right and left or left and right) back and forth then pass the ball. The total distance was 12 m.	
Exercise 2: Stop the ball (4 balls) after dribbling and following multiple changes of direction in 4-meters square. The total distance was 18 m.	
Exercise 3: Touch cones placed in a hexagon (2m side length) with preplanned order (N°1, N°2, N°3 and N°4) and then pass the ball. The total distance was 20 m.	
Exercise 4: Two meters acceleration with ball then slalom with the ball between 3 cones and finally pass the ball and after that performing a 5-meters acceleration without the ball. The total distance was 10 m.	

FIGURE 2 | Description of the various change-of-direction speed training exercises.

(+ 4.56%, effect size = 1.51; + 4.51%, effect size = 1.05; and –3.08%, effect size = 0.51, respectively) than pre-PHV (+ 2.77%, effect size = 0.85; + 2.91%, effect size = 0.54; and –1.56%, effect size = 0.20, respectively) (**Table 4**).

TABLE 2 | Intraclass correlation coefficients (ICCs) for relative reliability and coefficients of variation for absolute reliability of the applied physical fitness tests.

Measures	ICC	95% CI	% CV
CS-YBT (%)	0.91	0.81–0.96	1.59
5JT (m)	0.91	0.80–0.96	3.67
Sprint 10-m (s)	0.96	0.91–0.98	1.45
Sprint 30-m (s)	0.95	0.90–0.98	1.27
15 m-CoD (s)	0.96	0.92–0.98	2.55
15 m-CoD + B (s)	0.90	0.80–0.95	3.98

ICC, intraclass correlation coefficient; CI, confidence interval; CV, coefficient of variation (%); 5JT, five-jump test; CS-YBT, Y-Balance Ttest composite score; 15 m-CoD, change-of-direction without the ball; 15 m-CoD + B, change-of-direction with the ball.

DISCUSSION

This study sought to examine the effects of a 6-week CoD training program on dynamic balance, horizontal jump, CoD with and without the ball, and sprint performance in youth male soccer players of different maturity status (pre-PHV and post-PHV).

TABLE 3 | Participants' anthropometric characteristics by player's maturity status.

	Pre-PHV (n = 15)	Post-PHV (n = 15)	Cohen's d	p-value
Age (years)	10.9 ± 0.4	17.4 ± 0.3	18.40	0.001
PHV (years)	–1.5 ± 0.3	3.2 ± 0.5	12.20	0.001
Height (cm)	164.9 ± 5.0	177.3 ± 6.5	2.21	0.001
BM (kg)	55.0 ± 6.4	67.0 ± 7.2	1.82	0.001
BMI (kg/m^2)	20.2 ± 1.9	21.3 ± 1.9	058	0.13
BF (%)	9.9 ± 2.2	12.2 ± 2.7	0.93	0.02

Data are means ± standard deviations (SD). BM, body mass; BF, body fat; BMI, body mass index, PHV, peak height velocity.

TABLE 4 | Effects of 6-week CoD training program on dynamic balance, horizontal jump, speed 10- and 30-m linear sprint times, and CoD with and without the ball (15 m-CoD and 15 m-CoD + B) in male soccer players at different maturity status (pre-PHV and post-PHV) (mean ± SD).

Variables	Group	Before training	After training	Change%	Cohen's *d*	ANOVA *p*-value (η^2)		
						Time	Group	Time × group
CS-YBT (%)	Pre-PHV	76.28 ± 2.48	78.40 ± 1.61**	+ 2.77	0.85	0.001 (0.70)	0.001 (0.41)	**0.04** (0.14)
	Post-PHV	79.06 ± 2.39	82.66 ± 2.92**	+ 4.56	1.51			
5JT (m)	Pre-PHV	10.78 ± 0.58	11.09 ± 0.54**	+ 2.91	0.54	0.001 (0.74)	0.001 (0.73)	**0.02** (0.18)
	Post-PHV	12.35 ± 0.53	12.90 ± 0.52**	+ 4.51	1.05			
Sprint 10-m (s)	Pre-PHV	1.90 ± 0.05	1.88 ± 0.05**	–0.88	0.36	0.001 (0.78)	0.001 (0.71)	0.36 (0.03)
	Post-PHV	1.75 ± 0.05	1.73 ± 0.05**	–1.14	0.40			
Sprint 30-m (s)	Pre-PHV	4.24 ± 0.16	4.21 ± 0.16**	–0.66	0.18	0.001 (0.66)	0.001 (0.23)	0.37 (0.03)
	Post-PHV	4.08 ± 0.15	4.06 ± 0.14**	–0.54	0.15			
15 m-CoD (s)	Pre-PHV	3.29 ± 0.26	3.24 ± 0.27**	–1.56	0.20	0.001 (0.79)	0.001 (0.48)	**0.01** (0.22)
	Post-PHV	2.90 ± 0.17	2.81 ± 0.16**	-3.08	0.51			
15 m-CoD + B (s)	Pre-PHV	4.14 ± 0.36	4.11 ± 0.36**	–0.74	0.09	0.001 (0.53)	0.008 (0.43)	0.41 (0.02)
	Post-PHV	3.67 ± 0.17	3.63 ± 0.17**	–1.13	0.25			

***Significant difference between before and after training, $p < 0.05$. ES, effect size; 5JT, five-jump test; CS-YBT, composite score during the Y-Balance Test; 15 m-CoD, change-of-direction without the ball; 15 m-CoD + B, change-of-direction with the ball. Bold values represent statistically significant values and were therefore highlighted.*

The within-group analyses revealed that the inclusion of the CoD training program increased almost all of the outcome measures in both pre-PHV and post-PHV groups, although larger effects were observed in dynamic balance, horizontal jump, and CoD without the ball for the post-PHV group (see **Table 3**). To the authors' knowledge this is the first study to demonstrate the effectiveness of the CoD training program in improving balance, horizontal jump, CoD, and sprint performance in male preadolescent and adolescent soccer players and to specifically compare the influence of different maturity status on this outcome.

Focusing on the within-group analysis (comparison baseline–follow-up), after 6 weeks of CoD training program, the post-PHV group further enhanced their performance in the dynamic balance (CS-YBT), horizontal jump (5JT), and CoD (15-m shuttle run without the ball). The post-PHV young soccer players outperformed the pre-PHV group in measures of dynamic balance (CS-YBT). The principal mechanism of the training adaptations may be associated to the balance challenges related with CoD training.

The successful execution of the CoD exercise requires the ability to rapidly accelerate, decelerate, and change position from side-to-side. Indeed, in such demanding situations, the vestibular system must compensate and adjust as the CoD task requires a repeated shift in the center of gravity outside the base of support, which challenges bodily equilibrium (Hammami et al., 2017, 2021).

The ability to move the center of gravity outside the base of support and maintain good balance and stability is defined by metastability (Kibele et al., 2015) and is considered as a key component of athletic performance and soccer success. CoD training also has many advantages over a stationary balance training (Makhlouf et al., 2018). In fact, it is a dynamic, high-speed, explosive activity and therefore joining to the concept of training specificity in soccer. The importance of dynamic balance has been further argued in a 6-week agility training program that was conducted to a greater performance improvement (Zemkova and Hamar, 2010), while numerous authors have posited that improvement in balance performance or metastability may be correlated with change of direction or agility tasks (Mirkov et al., 2008; Hammami et al., 2017). The present study indicated that the CoD training program may have triggered acute mechanisms that contribute to a better dynamic balance performance in post-PHV soccer players. Since CoD imposes many perturbations during balance and stability, the ability to efficiently support static and dynamic balance (metastability) could positively improve athletic (i.e., soccer) performance (Jones et al., 2009).

There were time and group effects for the testing measures of horizontal jump (5JT), indicating general overall improvements in the post-PHV group. The specific performance changes might be partly attributed to physical influences from growth and maturation (Malina et al., 2004). Moreover, the prior soccer training of these elite players also plays a role; given that soccer involves sprinting, jumping, and CoD tasks (Stolen et al., 2005; Ramirez-Campillo et al., 2014), the lower legs would already be in a relatively highly trained mood (high muscle power performance) and may have been highly susceptible to this short bout of training for enhancing muscle power (i.e., horizontal jumping). Consequently, for pre-PHV soccer players, a longer duration or more frequent training program may be required to generate further training adaptations from muscle groups that undergo power activities on almost a daily basis.

The present results showed that the 15 m-CoD test was more improved in the post-PHV group. According to similar maturational studies (Zemkova and Hamar, 2010; Lloyd et al., 2013; Asadi et al., 2017; Hammami et al., 2018), it could be speculated that the high neural demand of rapidly changing directions required a stimulus that coincided with the natural adaptive response of the post-PHV participants, resulting in growth and maturation (Lloyd et al., 2013). Developmentally, post-PHV players experienced neuromuscular (e.g., improved motor unit recruitment and firing rate) and morphological changes (e.g., improved pennation angles) that facilitate force generation, in addition to cognitive maturation (Malina et al., 2004). Therefore, future studies investigating the effect of cognitive maturation on pre-planned performance development are warranted.

In addition, major morphological and neural changes occur with growth and maturation (Malina et al., 2004; Tonson et al., 2008). These asynchronously changing parameters in youth play an important role in the ability to adapt to a CoD-specific training stimulus (Eisenmann and Malina, 2003; Vanttinen et al., 2011). Hence, knowledge of when to apply an appropriate CoD training stimulus during long-term athlete development is essential for effective programming and improving athletic related-performance.

Moreover, since the CoD training program did not involve more advanced skill training with a soccer ball, it might be expected that soccer-specific coordination skills (i.e., 15 m-CoD + B) would not be positively affected by CoD training, although this assertion should empirically test. Finally, as maturation has been shown to contribute to the trainability of CoD ability (Lloyd et al., 2013), the rate at which these individuals are experiencing maturation may, in part, explain the variation in training response. Considering that responses to training stimuli can differ between these maturation groups (Lloyd et al., 2013), it would be beneficial to examine such effects in the future. In addition, although improvements in balance, horizontal jump, and CoD were evident within and between maturation groups, future studies should holistically examine the effects of the CoD training program in youth athletes accounting for changes, such as muscle action and muscle architecture, in addition to the effect on further physical components, such as lower-limb asymmetry, with consideration of injury prevention.

Although the present study presents a novel addition to the literature, which has, hitherto, not been reported, there are some limitations that warrant consideration. Firstly, we acknowledge the small sample size, which reduces our statistical power; however, this study merely presents a preliminary work, and not designed to be powered at the level of a randomized controlled trial, and provides a stepping stone for further work.

Secondly, the duration of the intervention may be regarded a limitation; indeed, only 6 weeks can be considered a relatively short duration, which may have precluded more marked changes in test variables. Nevertheless, these short periods are also dictated by training periodization over the course of a soccer season. In addition, we were not able to examine the underlying neuromuscular mechanisms responsible for the observed improvement in measures of physical fitness due to the lack of neurophysiological testing apparatus in the design of this study. Therefore, future studies are advised to include electrophysiological testing apparatus (e.g., electromyography), although researchers and practitioners are encouraged to consider the practical benefits with logistical demands of such testing.

Finally, the CoD test used in the present study contained different magnitudes of other physical components (e.g., hurdle jump) where anaerobic capacity is a critical factor in performance, making it difficult to discern whether changes in performance are due to increases in CoD ability or improvements in anaerobic capacity (Nimphius et al., 2018). Future research should consider the adoption of more ecological CoD tests.

CONCLUSION

The present study is, to the authors' knowledge, the first to examine the effects of a COD training program on balance, horizontal jump, and CoD performance in male youth soccer players of different maturation levels. Based on the extant literature (Zemkova and Hamar, 2010; Lloyd et al., 2013; Asadi et al., 2017) and the improvements found in the current study in balance, horizontal jump, and CoD performance in the post-PHV soccer players, a greater emphasis on prior CoD activities and training should be placed on younger athletes (pre-PHV soccer players) with less developed neuromuscular systems in order to improve efficacy of balance, power, and CoD training. The COD training program utilized in this study may help practitioners working with pre-adolescent and adolescent male soccer players to improve their training programs.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The study was conducted according to the latest version of the Declaration of Helsinki and the protocol was fully approved by the Local Ethics Committee of the National Centre of Medicine and Science of Sports of Tunis (CNMSS) before the commencement of the assessments. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

DS, OO, RH, NS, SC, AN, and HZ participated in the conception and design of the study. DS, OO, RH, MC, and AN were responsible for testing. DS, MC, CC, UG, SC, NS, and AH were responsible for data collection and statistical analysis. DS, RH, MC, CC, SC, AN, AH, UG, NS, HZ, and OO were responsible for the writing and finalization of the manuscript. All authors contributed to the manuscript and approved the submitted version.

FUNDING

The authors acknowledge the support of the Deutsche Forschungsgemeinschaft (DFG) and Open Access Publishing Fund of the University of Potsdam, Germany.

ACKNOWLEDGMENTS

We would like to thank the participants and the research assistants involved in the data collection.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer BD declared a past co-authorship with the authors CC and UG to the handling editor.

frontiers in Physiology

ORIGINAL RESEARCH
published: 24 June 2021
doi: 10.3389/fphys.2021.685804

Perceptual and Biochemical Responses in Relation to Different Match-Day +2 Training Interventions in Soccer Players

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OPEN ACCESS

Edited by:
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Reviewed by:
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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: 25 March 2021
Accepted: 24 May 2021
Published: 24 June 2021

Citation:
Trecroci A, Perri E, Lombardi G, Banfi G, Del Vescovo RD, Rosa EM, Alberti G and Iaia FM (2021) Perceptual and Biochemical Responses in Relation to Different Match-Day +2 Training Interventions in Soccer Players. Front. Physiol. 12:685804. doi: 10.3389/fphys.2021.685804

The aim of this study was to examine the impact of two different post-match training interventions on the subsequent recovery of perceptual and biochemical parameters after the game. In a crossover design, eight sub-elite players underwent a soccer-specific training (SST) and an active recovery (AR) regimen on the second day after a match (+48 h). Muscle soreness as well as muscle damage (creatine kinase, CK), inflammatory (C-reactive protein and interleukin 6), immunological (e.g., lymphocytes, neutrophils, and monocytes), and endocrine (cortisol) markers were obtained at baseline (−72 h), immediately after (0 h), and 72 h post-match (+72 h). AR promoted a higher restoration of muscle soreness values ($P = 0.004$, $\eta^2_p = 0.49$) together with a better restoration of CK within 72 h post-match compared with SST ($P = 0.04$, $\eta^2_p = 0.36$). Conversely, no significant ($P > 0.05$, $\eta^2_p < 0.91$) differences were observed in the recovery timeframe of inflammatory, immunological, and endocrine responses between SST and AR. Overall, AR elicited a quicker muscle soreness and CK restoration compared to SST intervention at 72 h post-match. Such information provides novel evidence-based findings on the appropriateness of different recovery strategies and may aid to improve the practitioners' decision-making process when two consecutive games are played within 3 days.

Keywords: football (soccer), fatigue, active recovery, congested schedule, physiology

INTRODUCTION

During the competitive soccer season, players often undergo congested fixture schedules where they are usually required to play multiple games within a very short period of time. This imposes pronounced biomechanical stress, which may consequently prevent players from optimally recovering during the following days. This condition can induce a prolonged fatigue status, which refers to a failure in maintaining the required task that was achievable within the pre-match time frame (Pyne and Martin, 2011). Indeed, players' fatigue status may be prolonged for several hours/days after a single match, causing performance reductions (e.g., sprint ability) (Dupont et al., 2010; Silva et al., 2018), neuromuscular impairments (e.g., maximal voluntary contraction)

(Krustrup et al., 2011; Draganidis et al., 2015; Silva et al., 2018; Trecroci et al., 2020), as well as perceptual discomfort (e.g., muscle soreness) and biochemical perturbations (e.g., muscle damage, inflammatory and immunological markers) (Silva et al., 2018). In particular, muscle soreness and uric acid (inflammatory marker) (Sanchis-Gomar et al., 2015) did not return to baseline levels before 48 h after a match (Ascensão et al., 2008; Fatouros et al., 2010), while plasma creatine kinase (CK) activity remained significantly three- to eight-fold higher during the next 72 h (Ascensão et al., 2008; Fatouros et al., 2010), indicating a muscle damage. Additionally, neutrophil and interleukin 6 were shown to be increased up to 48 h after a game (match day + 2) (Romagnoli et al., 2016). Thus, the exacerbated muscle damage and inflammatory and immune markers observed in the hours following a soccer game may play a determinant role for the slow recovery timeframe and the subsequent players' inability to reach optimal levels of readiness. Nonetheless, the restoration of selected biochemical parameters may also be further affected by the practices carried out in the days after the game (Ekstrand, 2004; Draganidis et al., 2015; Trecroci et al., 2020). While the vast majority of the studies have investigated the recovery strategies (Fatouros et al., 2010; Romagnoli et al., 2016), the current literature lacks solid scientific evidence regarding the most appropriate type of training [e.g., active recovery (AR) or soccer-specific training (SST) sessions] to be performed in the days following a match and its impact on subsequent restoration of physiological and performance markers.

Only few studies have examined the effect of post-game interventions on the following physiological response and exercise performance (Andersson et al., 2008, 2010) in female soccer players. Andersson et al. (2008, 2010) compared the impact of 1-h AR (non-soccer-specific session including submaximal cycling at 60% peak heart rate and resistance training at <50% one-repetition maximum) versus passive recovery on neuromuscular, biochemical (e.g., CK and uric acid), and perceptual responses during the 72-h period between two matches. The authors found that the AR failed to affect CK concentration, acid uric levels, and perceived muscle soreness. However, the ecological validity of the latter study may be questioned as the athletes' sport-specific needs in preparation of the next match-play were not considered. Of note, in a real scenario, players are supposed to practice their technical–tactical skill between two consecutive games. To the best of our knowledge, only one investigation (Trecroci et al., 2020) researched the effects of different field-based training interventions performed 2 days after the game on the subsequent recovery of physical and neuromuscular performance. Trecroci et al. (2020) compared 1 h of soccer-specific activities simulating a pre-match training session (i.e., small-sided games, attacking/defending solutions and offensive set pieces) versus ∼30 min of AR (i.e., low-intensity technical drills and straight-line jogging). It was demonstrated that low-intensity AR promoted a better restitution of knee flexor muscle force production in the post-game period (Trecroci et al., 2020). However, although novel information on the recovery kinetics of targeted physical and neuromuscular components was provided, the effect of different strategies on the time course of specific biochemical and perceptual parameters remains unknown. In particular, whether an augmented blood flow induced by high-intensity exercise may contribute to enhance the restoration of specific immunological and inflammatory markers is still unclear.

A better understanding on how and to which extent such variables could be affected by different field-based training interventions would provide new insight into the selection of the most appropriate training practices for emphasizing the recovery processes and maximizing players' readiness. This may have important implications when two or more games are separated by only few hours (i.e., 72 h). Thus, the aim of the present study was to assess the recovery kinetics of selected perceptual and biochemical parameters 72 h after a soccer match in relation to different types of match-day +2 training interventions.

MATERIALS AND METHODS

Participants

Nine young male sub-elite soccer players (age 17.7 ± 0.55 years, 177 ± 2.3 cm, body mass 65.85 ± 6.0 kg) who have been playing for a minimum of 8 years volunteered to participate in the study. All players were part of the same team competing in the U19 National League. Exclusion criteria were as follows: (i) history of febrile illness and lower-limb injuries in the 8 weeks prior to the study; and (ii) a compliancy of less than four training sessions and a game per week during the 7 days before the experimental period. Players, parents, or legal guardians were deeply informed about the research purpose and any potential risks of the experiment before given a written informed consent to participate. If under the age of 18, the player and his parents or legal guardian signed the written informed consent. The study was approved by the Ethical Committee of the Università degli Studi di Milano (32/16 approval number) in accordance with the Helsinki declaration.

Experimental Design

A crossover design was utilized to study the effects of two different training regimes carried out 48 h after the game on the recovery of post-match perceptual and biochemical variables measured 72 h after the game. The entire protocol was conducted during the in-season period and consisted of (I) initial procedures including a familiarization period, (II) a first experimental phase, (III) a 4-week washout period, and (IV) a second experimental phase (**Figure 1**). During both experimental phases, all players were monitored and tested on three different time points: 72 h before the match (baseline), immediately after the match (0 h), and 72 h post-match (+72 h). On the second day after the match (+48 h), the participants performed either an AR or a SST session based on different durations (30 min vs. 1 h) and intensity (low vs. high).

Each testing session included a blood sample collection as well as perceptual assessment (self-reported values of muscle soreness and quality of recovery). The match played consisted of a 90-min friendly game with no substitutions against a team of the same competitive level, and it was preceded by

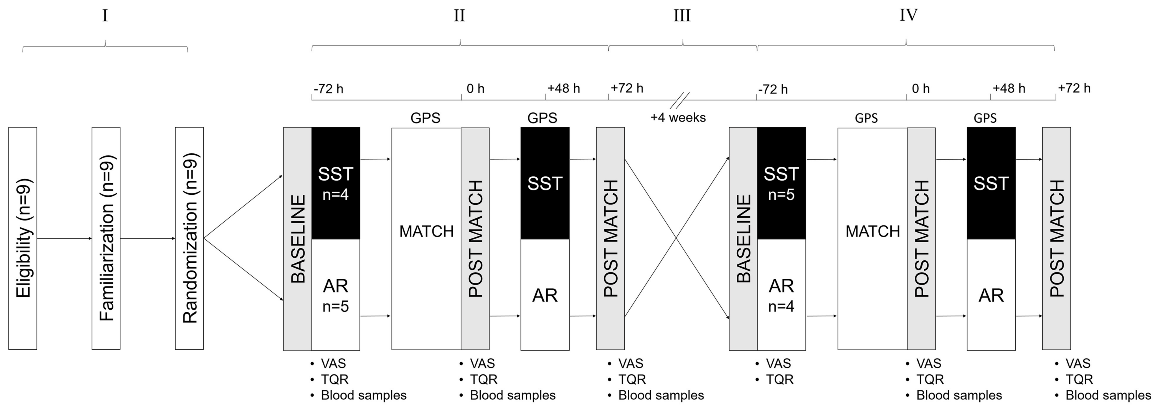

FIGURE 1 | A schematic representation of the experimental schedule. The group-specific training interventions were completed 48 h after the match, while VAS scores and blood samples were collected before (−72 h), immediately (0 h), and after (72 h) the match. GPS, global positioning system; SST, sport-specific training session; AR, active recovery session; VAS, visual analog scale; TQR, total quality of recovery.

a 15-min standardized warmup. Height and body mass were obtained 2 days prior to the match using a stadiometer (SECA 213, Germany) and a portable scale (SECA 813, Germany) to the nearest 1.0 cm and 0.1 kg, respectively. After 4 weeks, the participants swapped the group-specific interventions and completed the second experimental phase undergoing the same timeline and procedures as described above (**Figure 1**). The washout period served to minimize the influence of fatigue-induced carryover effects experienced by the players within the in-season schedule (Trecroci et al., 2020). As prior to the study, during the washout period, all players followed their in-season macrocycle training routine consisting of four ∼2-h sessions and a game per week. The weekly training content of each session was equally distributed throughout the washout period. The players did not experience any musculoskeletal issues, injury events, or diseases throughout both the experimental and washout periods.

Training Interventions

The day after the match, all participants were requested not to practice or to do any low-to-high physical activity or manual therapy, massages, or similar recovery strategies. On the second day after the game (+48 h), the participants performed either a SST or an AR session. Briefly, the STT lasted ∼60 min and consisted of warmup, small-sided games, and tactical drills, whereas the AR was constituted by ∼30-min light activities including low-intensity technical drills, dynamic stretching, and straight-line jogging (Trecroci et al., 2020). Overall, the experimental schedule (a resting session 24 h post-match and a training intervention 48 h post-match) followed the common post-match program (Impellizzeri et al., 2004).

Match-Play and Training Activities

Total and high speed run – i.e., >18 km/h – distances, estimated metabolic power (Osgnach et al., 2010), and distance covered at accelerating and decelerating (Gaudino et al., 2014) were monitored during the game and training sessions by a portable non-differential 10-Hz (standard error of measurement 5.1%, coefficient of variation <5%) (Kelly et al., 2014) global positioning system (GPS) integrated with a 400-Hz 3-D accelerometer, a 3-D gyroscope, a 3-D digital compass, and a 10-Hz 3-D magnetometer (Playertek GPS System; Kodaplay Ltd., Dundalk, Ireland). All GPS pods were turned on 15 min before each experimental session to favor an optimal acquisition of satellite signals. Moreover, each player used the same pod throughout the experimental period to avoid interunit error. Cardiovascular load [heart rate (HR)] by a dedicated belt connected to the GPS pod *via* Bluetooth signal (Playertek System; Kodaplay Ltd., Dundalk, Ireland) and rate of perceived exertion (RPE) by means of the Borg Category-Ratio–10 scale (CR10) were also recorded (Impellizzeri et al., 2004). The RPE was individually collected 20 min after each match and training session. All players were already familiar with the CR10 scale as routinely embedded in their weekly assessment procedure throughout the season.

Perception of Recovery

Perceived muscle soreness was evaluated using a 10-cm linear analog scale with labels that corresponded to "not pain" and "extreme pain" either end (Nosaka et al., 2002). This scale is a sensitive tool expressing an indirect measure of muscle damage (Saw et al., 2016; Silva et al., 2018) *via* subjective discomfort responses. Each participant marked his perceived level of pain in the thigh muscles. The soreness was recorded at baseline (−72 h), immediately after (0 h), and 72 h after (+72 h) the match to monitor perceptual discomfort linked to muscle fatigue. Total quality of recovery (TQR) encompassing a 6–20 Likert scale was also provided for obtaining the players' subjective state of recovery (Kenttä and Hassmén, 1998). The TQR scale ranged from "very very poor recovery" (corresponding to six points) to "very very good recovery" (corresponding to 20 points). TQR values were collected 30 min before starting warmup in both training sessions as well as prior to the match. Both soreness and TQR scores were used within the analysis to detect potential differences in recovery timeframe.

Biochemical Assays

Blood samples were collected on the field after 10 min of rest in a sitting position by standard antecubital venipuncture in both ethylenediaminetetraacetate di-potassium salt (K2-EDTA) spray-coated tubes and SST II Advance serum tubes (BD Vacutainer®, Becton Dickinson & Co., Franklin Lakes, NJ, United States), at the indicated time points (i.e., −72, 0, and +72 h). After sampling, blood tubes were inverted 10 times, following the manufacturer's instruction, allowed to clot for 30 min in the case of SST™ II tubes, stored at 4°C, and transported to the laboratory in a dedicated box at controlled temperature within 3 h. Once in the lab, K2-EDTA anticoagulated samples were homogenized for 15 min and assayed for the following hematological parameters on a Xn-10 Sysmex (Sysmex Co., Kobe, Japan): white blood cell (WBC) count (10^3 cells/ml), neutrophils (Neu, 10^3 cells/ml), monocytes (Mo, 10^3 cells/ml), and lymphocytes (Ly, 10^3 cells/ml). Serum, obtained following centrifugation (1,300*g*, 10 min, 25°C) of SST™ II Advance samples, was assayed for the following parameters: uric acid (UA, mg/dl), creatinine (sCr, mg/dl), creatine kinase (CK, U/L), high-sensitivity C-reactive protein (CRP, mg/dl) on an Architect c8000 (Abbott Co., Chicago, IL, United States), cortisol (μg/dl) on an i1000 Architect (Abbott), and interleukin 6 (IL-6, pg/ml) on a DSX (Dynex Technologies, Chantilly, VA, United States). Instruments were routinely checked using internal and external standard analyses.

During the experimental period, the participants continued with their ordinary nutritional habits as prior to the study. On the days of testing, they were instructed to follow a standardized meal plan that satisfied the macronutrient intake for athletes engaged in daily training (García-Rovés et al., 2014) and calculated based on the body mass of each player (Russell and Pennock, 2011). The standardized dietary intake was also kept during the washout period. The players did not consume any supplements throughout the experimental protocol.

Statistical Analysis

According to the assumption of normality assessed by the Shapiro–Wilk's test, paired *t*-tests were used to detect possible differences between the two matches. A two-way analysis of variance (ANOVA) with repeated measures was used to detect possible interactions (time × intervention) and significant main effects of time and intervention throughout the two (0 h and +72 h) and three time points (baseline, 0 h, and +72 h) for perceptual and biochemical variables, respectively. In case of significant interaction, Bonferroni's adjustment was used for multiple comparisons. Partial eta squared (η^2_p) was used to estimate the magnitude of the difference for interactions, and the thresholds for small, moderate, and large effects were defined as 0.01, 0.06, and 0.14, respectively. The effect size (ES) (Cohen, 1988) of the multiple comparisons was also calculated to display the within-group differences for SST and AR. The ES was classified as trivial (ES < 0.2), small (0.2 < ES < 0.5), moderate (0.5 < ES < 0.8), and large (ES > 0.8). The coefficient of variation (CV) was also computed to explore intra-individual variability at baseline (for perception of recovery variables) and 0 h (for perception of recovery variables and biochemical markers) over the experimental phases. All analyses were performed using the IBM SPSS Statistics (v. 21, New York, NY, United States), and data are shown as mean ± standard deviation (SD) with 95% confidence intervals (CI) in squared brackets. An α-value = 0.05 was set as the criterion level of significance.

RESULTS

Game Load

The two matches played during the first and the second experimental phase were similar in terms of total distance (9,938 ± 1,185 m vs. 9,889 ± 1,100 m), high speed run distance (729 ± 117 m vs. 781 ± 202 m), metabolic power (9.03 ± 1.17 vs. 8.86 ± 1.14 W/kg), as well as distance covered at accelerations of 1–2 m·s^{-2} (802.07 ± 136 m vs. 900.03 ± 193 m), 2–3 m·s^{-2} (194.47 ± 36 m vs. 226.31 ± 49 m), and >3 m·s^{-2} (41.47 ± 16 m vs. ± 49 11 m) ($P > 0.05$).

Training Load

The detailed load variables of both SST and AR interventions are shown in **Table 1**. In SST, the average time spent between 75% and 85% and above 85% of HRmax was ∼13.8 and ∼4.5 min, respectively, whereas only 1.7 min between 75 and 85% HRmax was recorded for AR. Furthermore, the overall distances covered at accelerations (from 1 to 3 m·s^{-2}) and decelerations (from −1 to −3 m·s^{-2}) were more than fourfold higher in SST compared to AR.

Perceptual Response

A significant [$F_{(1,16)} = 7.901$, $\eta^2_p = 0.497$, $P = 0.004$] interaction was found in muscle soreness, which moved differently ($P < 0.05$) after the SST and AR interventions (baseline, 1.94 ± 0.91 [1.24 to 2.64 95% CI] and 1.88 ± 0.48 A.U. [1.51 to 2.26 95% CI]; 0 h, 5.22 ± 0.83 [4.66 to 5.78 95% CI] and 5.00 ± 0.82 A.U. [4.37 to 5.62 95% CI]; +72 h, 3.61 ± 0.61 [3.14 to 4.07 95% CI] and 1.83 ± 0.96 A.U. [1.29 to 2.27 95% CI]) (**Figure 2**). Specifically, after SST, the average soreness score from 0 to +72 h improved significantly less ($P = 0.33$, ES = 2.2) compared with AR ($P < 0.0001$, ES = 4.2). The CV was 14 and 11% at baseline and 0 h over the two experimental phases, respectively. Regarding TQR, neither significant main effects of time ($P = 0.81$) and intervention ($P = 0.14$) nor a significant interaction ($P = 0.22$) was observed between SST and AR interventions from 0 to +72 h (baseline, 16.31 ± 1.68 [15.22 to 18.01 95% CI] and 16.43 ± 1.65 A.U. [15.36 to 18.08 95% CI]; 0 h, 16.18 ± 1.51 [14.93 to 17.18 95% CI] and 16.43 ± 1.14 A.U. [15.69 to 17.53 95% CI]; +72 h, 15.43 ± 1.39 [14.53 to 16.69 95% CI] and 16.50 ± 1.1 A.U. [15.78 to 17.33 95% CI], respectively) with ESs <0.34. The CV was 0.5 and 7% at baseline and 0 h over the experimental phases, respectively.

Biochemical Measurements

Regarding biochemical markers, a significant [$F_{(1,16)} = 4.096$, $\eta^2_p = 0.369$, $P = 0.04$] interaction was found in CK levels (**Figure 3**). Before both interventions, CK levels increased

TABLE 1 | Perceived load assessed by CR10 Borg scale; kinematic, metabolic, cardiovascular, and mechanical load parameters assessed by GPS for both interventions.

Training interventions	RPE (a.u.)	Total distance (km)	Metabolic power score (W·kg^{-1})	Time in HR zone 75–85% HRmax (s)	Time in HR zone 86–96% HRmax (s)	Distance covered at acceleration of 1–2 m·s^{-2} (m)	Distance covered at acceleration of 2–3 m·s^{-2} (m)	Distance covered at deceleration of 1–2 m·s^{-2} (m)	Distance covered at deceleration of 2–3 m·s^{-2} (m)
SST	3.6 ± 1.1	4.1 ± 0.4	3.6 ± 0.4	827 ± 117	270 ± 320	352 ± 62	102 ± 38	420 ± 80	133 ± 42
AR	1.1 ± 0.4	1.8 ± 0.3	1.8 ± 0.3	106 ± 45	0 ± 0	93 ± 25	0 ± 0	123 ± 43	0 ± 0

GPS, global positioning system; SST, soccer-specific training session; AR, active recovery session; RPE, rating of perceived exertion; HR, heart rate; HRmax, maximal heart rate.

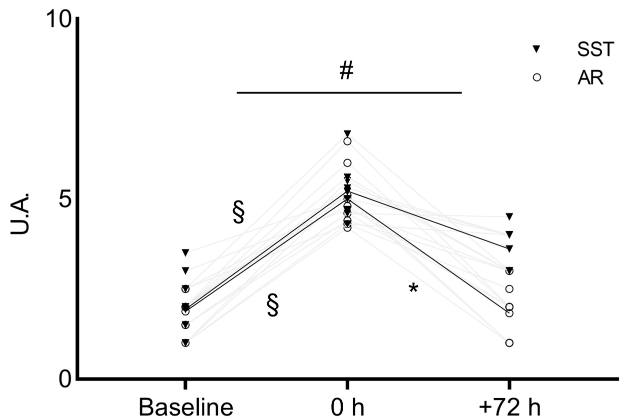

FIGURE 2 | A graphical representation of the recovery pattern of muscle soreness. The bold lines identify the means of both SST and AR. #Significant ($P < 0.05$) interaction throughout the time points (baseline, 0 h and +72 h). § Significant ($P < 0.05$) difference between 0 h and baseline for SST and AR. *Significant ($P < 0.05$) difference between +72 h and 0 h for AR. SST, sport-specific training session; AR, active recovery session; VAS, visual analogue scale.

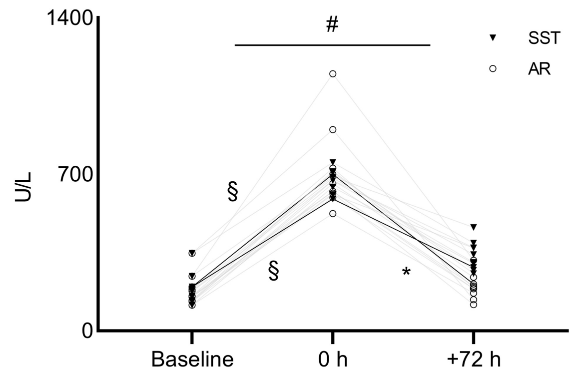

FIGURE 3 | A graphical representation of the recovery pattern of CK. The bold lines identify the means of both SST and AR. #Significant ($P < 0.05$) interaction throughout the time points (baseline, 0 h, and +72 h). § Significant ($P < 0.05$) difference between 0 h and baseline for SST and AR. *Significant ($P < 0.05$) difference between +72 h and 0 h for AR. SST, sport-specific training session; AR, active recovery session; CK, creatine kinase.

remarkably from baseline to 0 h in SST (from 186.12 ± 84.57 [128.2 to 239.6, 95% CI] to 570 ± 232 U/L [651 to 714, 95% CI]; P = 0.007, ES = 2.2) and in AR (from 186.12 ± 84.57 [128.2 to 239.6, 95% CI] to 680 ± 343 U/L [563.5 to 863, 95% CI]; $P < 0.0001$, ES = 2.0). After SST, CK levels did recover significantly less from 0 to +72 h (from 570 ± 232 to 283.87 ± 98.33 U/L [291.1 to 391.7, 95% CI]; P = 0.06, ES = 1.6) compared with AR (from 680 ± 343 to 209 ± 98.16 U/L [150.2 to 239, 95% CI]; $P < 0.0001$, ES = 1.9). The CV was 11% at 0 h over the two experimental phases. The absolute values of the other biochemical variables expressing muscle damage (sCr and CRP), inflammation (UA, CRP, and IL-6), endocrine (cortisol), and immunological markers (WBC, neutrophils, lymphocytes, and monocytes) are shown in **Table 2** at each time point. No significant interactions were found between SST and AR interventions for all markers ($P > 0.05$). The analysis showed a significant main effect of time for all parameters ($P < 0.005$), except for CRP and lymphocytes, which did not change significantly compared throughout the time points ($P > 0.05$) (**Table 2**). Subsequent analyses revealed that all variables changed significantly ($P < 0.01$) from −72 to 0 h and from 0 to +72 h. *Vice versa*, all the mentioned markers did not display significant differences in the main effect of intervention ($P > 0.05$). The CV of all markers at 0 h ranged from 6 to 65% over the two experimental phases.

DISCUSSION

The present study is the first to examine the time course of recovery of perceptual and biochemical variables after 72 h following a soccer match in response to different training strategies performed 48 h after the game (match-day +2). The most important findings were that compared to SST, AR promoted a better restoration of CK together with a higher normalization of VAS values within 72 h post-match, whereas no differences were observed in inflammatory, immunological (WBC, and Ly), and endocrine markers between the two training interventions.

Creatine kinase represents the most frequently used marker to monitor the muscle damage in several team ball sports (Doeven et al., 2018), and the results from our study may indicate that performing a SST session 2 days after a match could potentially cause prolonged muscle damage and soreness in the following day (+72 h). This is in line with recent systematic reviews showing a substantial elevation of muscle damage markers (e.g., CK) until 72 h after the game (Doeven et al., 2018; Silva et al., 2018).

TABLE 2 | Descriptive statistics (mean ± SD) for all blood markers obtained in the two treatments (SSG and AR) with *F*-values, partial eta squared ($\eta_p{}^2$), and *P*-values derived from the two-way ANOVA repeated measures for interaction (time × intervention) and main effects of time and intervention.

Markers	Intervention	Before Match (-72 h)	Post-Match (0 h)	Post-intervention (+72 h)	Time × Intervention			Time			Intervention		
					$F_{(2,14)}$	$\eta\ p^2$	*P*	$F_{(2,14)}$	$\eta\ p^2$	*P*	$F_{(1,7)}$	$\eta\ p^2$	*P*
UA(mg/dl)	SST	4.76 ± 1.03	5.93 ± 1.19*#	5.03 ± 1.28	1.139	0.140	0.34	18.788	0.72	**<0.001**	2.536	0.266	0.15
	AR		5.75 ± 1.08*#	4.73 ± 0.96									
sCr(mg/dl)	SST	0.84 ± 0.10	1.19 ± 0.24*#	0.93 ± 0.19	0.700	0.91	0.51	25.505	0.78	**<0.001**	1.702	0.196	0.23
	AR		1.12 ± 0.10*#	0.87 ± 0.07									
Cortisol(μg/dl)	SST	6.41 ± 1.84	14.03 ± 6.37*#	5.52 ± 1.29	0.506	0.067	0.61	13.746	0.66	**<0.001**	0.512	0.068	0.49
	AR		12.12 ± 5.28*#	5.51 ± 1.44									
CRP(mg/dl)	SST	0.11 ± 0.10	0.20 ± 0.22	0.13 ± 0.13	2.244	0.243	0.14	0.089	0.013	0.916	3.049	0.303	0.12
	AR		0.05 ± 0.31	0.08 ± 0.09									
IL-6(pg/ml)	SST	<1.84	3.74 ± 2.30*#	<1.84	0.558	0.074	0.58	5.445	0.43	**0.018**	0.558	0.074	0.47
	AR		3.06 ± 2.28*#	<1.84									
WBC(10^3/ml)	SST	8.99 ± 1.65	12.11 ± 3.05*#	8.30 ± 1.27	0.010	0.001	0.92	39.361	0.83	**<0.0001**	0.112	0.014	0.74
	AR		12.27 ± 2.65*#	8.54 ± 1.94									
Neu(10^3/ml)	SST	5.19 ± 1.13	8.40 ± 3.05*#	4.55 ± 1.18	0.048	0.006	0.83	28.495	0.78	**<0.001**	0.107	0.013	0.75
	AR		8.52 ± 2.19*#	4.83 ± 1.41									
Ly(10^3/ml)	SST	2.89 ± 0.69	2.52 ± 0.55	2.82 ± 0.82	0.154	0.019	0.70	1.653	0.17	0.235	0.109	0.012	0.75
	AR		2.59 ± 0.54	2.81 ± 0.68									
Mo(10^3/ml)	SST	0.78 ± 0.18	1.03 ± 0.14*#	0.73 ± 0.06	0.239	0.029	0.63	134.560	0.94	**<0.0001**	0.012	0.002	0.91
	AR		1.01 ± 0.19*#	0.74 ± 0.17									

*SST, sport-specific training session; AR, active recovery session; UA, uric acid; sCr, creatinine; CK, creatine kinase; CRP, C-reactive protein; IL-6, interleukin-6; WBC, white blood cells; Ly, lymphocytes; Mo, monocytes. *Significant difference toward −72 h. #Significant difference toward +72 h. The bold values indicate the significance of the main effects of time.*

Besides the biochemical stress imposed by a soccer match, such a prolonged time window may also be due to a cumulative post-match daily practice by means of highly demanding activities (Banfi et al., 2012).

However, while the recovery kinetic of neuromuscular and biological parameters following a football game is well known (Ascensão et al., 2008; Nédélec et al., 2012, 2013; Draganidis et al., 2015; Romagnoli et al., 2016; Doeven et al., 2018; Silva et al., 2018; Kunz et al., 2019), only few studies have investigated the effects of different training sessions on the subsequent restoration of perceptual and biochemical variables (Andersson et al., 2008, 2010). A study compared the effects of passive versus AR (including submaximal cycling at low-intensity resistance training) between two matches separated by 72 h in elite female soccer players (Andersson et al., 2008). The AR was scheduled 22 and 46 h after the first match, and the players were tested at baseline, 0, 5, 21, 27, 45, 51, and 69 h after the first match, as well as immediately after the second match. Overall, Andersson et al. (2008) did not find significant differences at any time points on the recovery timeframe of muscle soreness and biochemical (e.g., CK) variables between active and passive recovery. Interestingly, following the first match, muscle soreness and CK values returned to baseline within 72 h (i.e., after 51 and 45 h, respectively) after both recovery interventions, which is in line with our findings. Nonetheless, Andersson et al. (2008) utilized a combination of cycling and general resistance training exercises, which do not mirror the sport-specific needs of the players and do not resemble the training practice routine usually carried out between multiple weekly games. Therefore, in the present investigation, SST was organized to meet the players' technical, tactical, and conditioning demands during a typical pre-match session. These practices often require players to perform several explosive concentric and eccentric actions (e.g., sprints and changes of directions), which, as shown in a previous study (Trecroci et al., 2020), they seem to become somehow demanding especially for knee flexors. As such, the higher load imposed by SST compared to AR after 48 h post-match may likely have contributed to slow down the restoration of knee flexor muscle force production (Trecroci et al., 2020), thus prolonging the recovery of the related perceptual and biochemical variables up to 72 h.

The fact that SST likely elicited bigger exercise-induced muscle damage, as shown by CK changes, was also reinforced by the concurrent increase in perceived muscle soreness at 0 h. According to Nedelec et al. (2014), the number of short sprints (<5 m) performed during the match was correlated to the muscle soreness measured at both 48 and 72 h after the game. Therefore, different recovery patterns of muscle soreness scores detected between SST and AR intervention may likely be attributed to their inherent task-specific characteristics. Moreover, the fact that muscle soreness scores decreased significantly after AR would reflect a better restoration of perceptual responses linked to muscle fatigue following low-intensity training on match-day +2 (e.g., straight-line jogging).

On the contrary, no differences were observed in the time course of inflammatory (CRP and IL-6), immunological (WBC, lymphocytes, neutrophils, and monocytes), and endocrine (cortisol) markers between SST and AR, indicating that small doses of high-intensity exercise performed 2 days after the game would not seem to compromise the restoration in most of the selected biochemical variables. This is in line with

Mohr et al. (2016) who, examining the effect of playing three competitive games in 1 week (with one training session between games) (Mohr et al., 2016), reported that, except for CRP (which was still high after the second/middle match), the targeted inflammatory, immunological, and endocrine markers returned to baseline within 72 h after the first match. In support, the CRP as well as lymphocyte levels from the present study did not change significantly throughout the time span and were similar in both SST and AR interventions. What emerges from the subjects' response to the intervention is that prominent markers of inflammation and systemic stress (UA, sCr, cortisol, CRP, and IL-6) reflected the situation observed in AR for CK, i.e., a greater decrease during recovery. Although this difference did not reach statistical significance, they are possibly indicative of a better adaptation, in all subjects, consequent to the AR intervention rather than to an additional training session. However, since most of the studies examined the time course of the post-match recovery without considering the effect of the daily practice and/or specifying the drills performed during each training session, it makes it difficult to further direct comparisons with the present findings. Thus, future research is warranted to better clarify the role of daily practices on the recovery pattern of perceptual and biochemical parameters after a match or within a congested fixture period.

Overall, the results from the present study taken together with those of a previous investigation (Trecroci et al., 2020) indicate that, compared to AR, delivering high-intensity exercise 2 days after a game impairs the recovery of selected physiological (CK), perceptual (muscle soreness), and neuromuscular/mechanical components (muscle flexors MVC, soreness, and CK) but does not have a negative impact on single- and repeated-sprint capacity. Thus, it appears that the beneficial effect of post-game AR or low-intensity activities seems to be linked more to an augmented clearance of those parameters reflecting exercise-induced muscle damage, rather than to a better restoration of exercise performance and its relative biochemical variables. Of note, future research should also evaluate the changes of perceptual and biochemical responses in relation to AR and SST matched for training duration. On one hand, a shorter duration session (30 min versus 1 h) may contribute to change the training load and players' perceptual responses, perhaps limiting data interpretation. On the other hand, employing different forms of low- to high-intensity and low- to high-duration sessions (AR and SST) may contribute to infer practical information on the recovery of perceptual and physiological markers within a realistic scenario.

The current novel findings may also be of practical relevance as they can aid to get additional knowledge in the decision-making process when prescribing specific training interventions. We cannot rule out the fact that a higher intensity or grater duration of high-intensity exercise could have led to different physiological responses on the following day. On the other hand, the current data, combined with those from Trecroci et al. (2020), seem to suggest that a low dose of high-intensity work performed 2 days after the game is not detrimental *per se* for subsequent exercise performance. However, future research is warranted to directly test this hypothesis as well as to examine its effects on both additional fitness improvements and fatigue/injury rate maintenance over a longer period. Furthermore, it should be acknowledged that the small sample size employed in the present investigation may be considered as a limitation when interpreting the study outcomes, although the utilization of a crossover design certainly strengthened the results. However, further studies will have to recruit larger sample sizes in order to confirm the findings from the current research.

CONCLUSION

This study showed that the recovery pattern of match-induced perceived muscle soreness and CK perturbations was not the same when SST or AR intervention were performed 48 h after the game, with AR eliciting a quicker VAS and CK restoration compared to SST intervention at 72 h post-match. No changes in the time course recovery of inflammatory, immunological, and endocrine markers were displayed between the two interventions. Additional studies including competitive games and elite players are warranted to induce higher workload and greater ecological match-related fatigue effects. Furthermore, future research should aim at employing larger sample size for increasing the statistical power. Lastly, it would be of interest to understand how the different training strategies (low- vs. high-intensity exercise) carried out between multiple weekly matches may affect fatigue, physiological adaptations, and possible performance changes in the long term (e.g., after 6–8 weeks).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of the University of Milan. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AT, EP, and FI conceived and conducted the research. AT, EP, GL, GB, RD, and ER performed formal analysis and data curation. AT and FI wrote and drafted the manuscript. GA and FI supervised the experimental procedures. All authors have read and approved the final version of the manuscript and agreed with the order of presentation of the authors.

ACKNOWLEDGMENTS

The authors would like to thank Marco Duca (Ph.D.) and Gaetano Pitoia for their precious technical support that contributed to improve the methodological approach during the experimental phase of the study.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
published: 29 June 2021
doi: 10.3389/fphys.2021.698463

Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey

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Edited by:
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Reviewed by:
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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *21 April 2021*
Accepted: *31 May 2021*
Published: *29 June 2021*

Citation:
Fernández D, Moya D, Cadefau JA and Carmona G (2021) Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey. Front. Physiol. 12:698463. doi: 10.3389/fphys.2021.698463

The aims of this study were 3-fold: firstly, to present an integrative approach to external and internal load dynamics for monitoring fitness and fatigue status of specific in-court rink hockey training sessions in a standard microcycle; secondly, to assess the differences between training sessions and matches; the third and final aim was to assess the association between external and internal load metrics. The external load, using a local positioning system, and internal load, using the declared rate of perceived exertion, were measured during 23 in-season microcycles for nine top-level players. Training load data were analysed with regard to the number of days before or after a match [match day (MD) minus or plus]. In relation to the first aim, internal and external load metrics merged into a single integrated system using pooled data *z*-scores provided an invisible monitoring tool that places the players in the fitness-fatigue continuum throughout the different microcycle sessions. In this regard, MD-4 and MD-1 sessions tend to place, with a low dispersion, the players in a "low external and internal load" zone. On the contrary, in MD-3 and MD-2 sessions, as well as in MD, in which higher loads were recorded, most of the players were within a "high external and internal load" zone with a tendency towards dispersion towards the fitness or fatigue zones. Finally, and with regard to the second and third aims, an inverted "*U*-shape" load dynamic related to the specific goals of each training session was the main finding in terms of comparison between MD; a load peak between MD-3 and MD-2 sessions and a significant decrease in all the load variables in MD-1 sessions were found; and high-to-low correlations were found between external and internal load metrics. This study presents an integrative approach to the external and internal load of players for monitoring fitness and fatigue status during a standard microcycle in rink hockey that might provide team sport staff members with a deeper understanding of load distribution in the microcycle in relation to the match.

Keywords: team sport, load control, ultrawide-band, LPS, GPS

INTRODUCTION

Workload in the context of sports training has been defined as the input variable which, assuming a certain level of stress, is manipulated to obtain a desired response (Impellizzeri et al., 2019). While training load is totally manipulable, competition load, due to its intrinsic characteristics such as results, place in the league table, stage of the season or type of league, is much less so and is limited to the possibility of regulating player exposure to it (minutes of play). Load can be described as internal or external (Impellizzeri et al., 2019). External load (EL) is the work completed by the player independently of his or her internal characteristics; for example, it is described in terms of distance, accelerations, decelerations, or sprints, among others (Varley and Aughey, 2013). The resulting physiological, psychological, and biomechanical stress imposed, described as internal load (IL), drives player adaptation response (Vanrenterghem et al., 2017). The outcome of any training intervention is therefore the consequence of both EL and IL, hence reliable monitoring tools are crucial to the optimisation of athletic performance (Impellizzeri et al., 2019) and to a better understanding of the factors affecting sport performance and recovery, since the uncoupling or divergence of EL and IL may differentiate between a non—fatigued and a fatigued athlete (Thorpe et al., 2017). Current models of the fitness—fatigue relationship use the association between EL and IL (Delaney et al., 2018), considering "fatigue" as the ability to complete a task or training session with an altered IL response which recent had been achievable with a lower IL response and "fitness state" as the opposite, the ability to accumulate a given EL with a lower IL response.

Thanks to tracking technology, athletes, coaches and sport scientists, can easily compile EL parameters to help practitioners and coaches to plan, evaluate, structure and optimise their training methodology (Borresen and Lambert, 2009). The use of electronic performance and tracking systems has helped to compare competition demands to training session drills and consequently modulate the intensity and volume of these training sessions according to the match day (Buchheit et al., 2014). Moreover, the use of subjective scales to record the declared exertion also makes it possible to obtain information about IL (Foster et al., 2001).

The organisation of training loads can be divided into macrocycles, mesocycles and microcycles (Naclerio et al., 2013). These divisions make it possible to organise the load from very large time cycles (for example macrocycles that encompass two seasons), through mesocycles that group several weeks or months of training, up to weekly microcycles. The most recent research in team sports is beginning to identify the microcycle as the most important planning unit in this type of sport in this specific case, understanding the microcycle not as the training week, but as the time that passes between one game and another (Tarragó et al., 2019). Indeed, many studies have provided comprehensive information about EL of outdoor elite team sports during matches, and some studies have furnished the same information about indoor elite team sports (Vázquez-Guerrero et al., 2019; Gómez-Carmona et al., 2020; Ribeiro et al., 2020), including high-intensity actions and metabolic variables. Research relating elite teams' in-season microcycles in outdoor sports is on the increase (Akenhead et al., 2016; Martín-García et al., 2018; Oliveira et al., 2019) but is virtually non-existent in indoor sports (Illa et al., 2020).

Being an indoor sport, rink hockey is a team sport involving skates and a stick and is characterised by high-intensity actions such as accelerations, decelerations, sprints, and changes of direction (Fernández et al., 2020b). Rink hockey is played in a 40 × 20 m court like futsal or handball, but with fences, a structural difference that means that there are fewer interruptions than in these other sports. It is played by two teams of four players and a goalkeeper, and official matches have two halves of 25 min; the number of players and the court size make rink hockey more similar to futsal than to basketball and handball in terms of density of players. Finally, the use of roller skates makes the movement of the players on the court much easier; they are able to cover large distances, sometimes without effort. Finally, decelerations and accelerations are the key actions in this sport (Fernández et al., 2020b). While the use of technology in certain team sports modalities has increased in the last decade, research into conditional demands is scant. Some research has addressed official matches (Merino Tantiña et al., 2014; Fernández et al., 2020b) and the most demanding passages in certain drills (Fernández et al., 2020a), although microcycle training load dynamics has never been described.

Accordingly, this research pursued three aims: (i) to present an integrative approach to EL and IL dynamics for monitoring the fitness and fatigue status in the specific in-court training sessions of an elite rink hockey team for a standard one-match-per-week microcycle; (ii) to evaluate the differences in EL and IL metrics between training sessions and match; and (iii) to assess the association between EL and IL metrics.

MATERIALS AND METHODS

Participants

Elite professional rink hockey players (n = 9, age: 29.8 ± 5.77 years, weight: 79.5 ± 5.50 kg, height 180.4 ± 4.03 cm, all measurements mean ± standard deviation) participated voluntarily in the study, whereas the goalkeepers were not included. In the two seasons analysed, the team won the Spanish First Division championship and seven of the nine players of the sample played for their respective national teams in official tournaments. The data analysed came from daily player monitoring, in which player activities were routinely measured throughout the season. The experimental procedures used in this study were approved by the local Ethics and Scientific Committee and all the players signed an informed consent form before participating.

Abbreviations: EL, external load; IL, internal load; declared RPE, declared rate of perceived exertion; s-RPE, session rate of perceived exertion; MD, match day; MD-x, match day [MD] minus X days; DT, distance travelled; HSS, high-speed skating; ACC, high-intensity accelerations; DEC, high-intensity decelerations; ES, effect size.

Methodology

A retrospective observational study was carried out during the 2018–2019 and 2019–2020 competitive seasons (in the latter only until March 2020 due to COVID-19). A non-experimental descriptive method was used to identify the demands of rink hockey microcycle training sessions and matches and to evaluate the differences between days. A correlation analysis was conducted to describe the relationship between EL and IL metrics. The training load data were analysed with regard to the number of days before the match [match day (MD) minus X days] (Akenhead et al., 2016).

As it has been noted in the introduction, the microcycle it is the most important programming unit in team sports training. Tarragó et al. (2019) defined a microcycle as the time that elapses between competitive matches, and stated that its goal is to achieve the best training possible and consider the loads of the competitive matches within the dynamic of the weekly load, considering them the most important factor that affects the other sessions. The number of competition matches per week, days between matches and the physical condition of the players and the team, among other conditioning factors, affected the structure of each microcycle throughout the season. Due to all these variations, the inclusion criteria for the standard microcycles analysed were: (1) microcycles with only one match per week, (2) microcycles with four training sessions before the match, (3) microcycles with 1 day of rest after the previous match, and (4) microcycles in which the matches were official. Once the microcycles had been chosen, the inclusion criteria for the players analysed in each session were: (1) the player had to complete the entire session and (2) the player had to be available for the match. With these criteria, a total of 23 in-season microcycles were chosen out of a total of 75, with 20 MD-4 sessions, 23 MD-3 sessions, 20 MD-2 sessions, 11 MD-1 sessions, and 8 MD official matches. The mean durations (and standard deviations) of the sessions were, 62.3 ± 4.26 min for the MD-4, 85.4 ± 4.91 min for MD-3, 76.5 ± 8.46 min for MD-2, 56.1 ± 3.24 min for MD-1, and 90.4 ± 4.99 min for MD. The missing session data (for example, only 11 MD-1 sessions of the 23 microcycles were analysed) were due to factors beyond the researcher's control (e.g., technical issues with equipment) or because training sessions had been arranged on other training courts and facilities for logistical and schedule reasons. The matches and specific in-court training sessions analysed were always played on the same court (always at home), ensuring the same environmental conditions.

The training sessions of the microcyles analysed in this research were always comprised of an integrated content (i.e., tactical, technical, and physical factors were amalgamated) and in line with the structured training and structured microcycle methodology (Tarragó et al., 2019). The main goals and drills used in each training session are provided in **Figure 1**.

Procedures

Data logging to evaluate EL was performed with a local positioning system (WIMU PRO™, Realtrack Systems SL) and its corresponding software (SPRO™, Realtrack Systems SL, version 962). The devices were fitted to the upper back using tight harnesses. The WIMU PRO™ features four 3D accelerometers (full-scale out output ranges are ± 16 g, ± 16 g, ± 32 g, ± 400 g, 100 Hz sample frequency), three gyroscopes (8,000°/s full-scale out output range, 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a GPS (10 Hz sample frequency), and ultra-wideband (18 Hz sample frequency). The ultra-wideband system was installed on the court as follows: six antennae with ultra-wideband technology were placed 5 m away from the perimeter line of the field. The WIMU PRO system presented a high intra-class correlation coefficient value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85) and a good % technical error of measurement: two (Bastida Castillo et al., 2019).

The following variables were calculated in absolute terms to describe EL: distance travelled in metres (DT; m); high-speed skating, distance covered above 18 km/h in metres (HSS >18 km·h^{-1}; m); player load, vector magnitude, expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100 in arbitrary units (PL; AU); number of high-intensity accelerations (ACC; >2 m·s^{-2}; n) and number of high-intensity decelerations (DEC; >2 m·s^{-2}; n). All of these variables were selected because they were the most commonly used ones in other competition load descriptive studies and the thresholds used were the ones emphasised most in indoor sport research and previously described in rink hockey (Fernández et al., 2020b).

Each player's declared rate of perceived exertion (declared RPE) was collected ∼30 min after each specific in-court training session or match using the 0–10 point Borg's rate of perceived exertion scale modified by Foster et al. (2001), with its respective verbal anchors, in order to collect subjective IL estimations. All the players were familiar with the use of the scale. A smartphone app was used to avoid bias and maintain subjectivity in player response. Subsequently, specific in-court session declared RPE (s-RPE) was calculated by multiplying the specific session (or game) duration in minutes by the individual declared RPE scores for the training (or game) and was presented in arbitrary units (a.u.) (Foster et al., 2001). s-RPE has been proposed as a cost-effective alternative to heart rate-based methods as a global measure of training intensity that may more accurately quantify IL in intermittent sports (Impellizzeri et al., 2004; Paulson et al., 2015). Both declared RPE (0–10 point scale) and s-RPE (a.u.) results were used for further analyses.

Statistical Analysis

All statistical analyses were conducted with RStudio version 1.3.1093 (RStudio, Inc.) and "readxls," "tidyr," "dplyr," "ggridges," "plyr," "ggplot2," "scales," "viridis," "pipeR," "effsize," "bootES," "officer," and "rvg" packages. Descriptive results were reported as mean ± standard deviation and a z-score analysis was conducted with the pooled s-RPE data and the mean of all z-score EL variable pooled data. The data failed all the tests for homogeneity of variance (Levene's test) and most of the variables and MD for normality (Shapiro–Wilk test). A bootstrap confidence interval (CI) approach was used to perform the hypothesis test to assess the differences between MDs because the assumptions of this method were aligned with our data (Tian, 2010). A residual

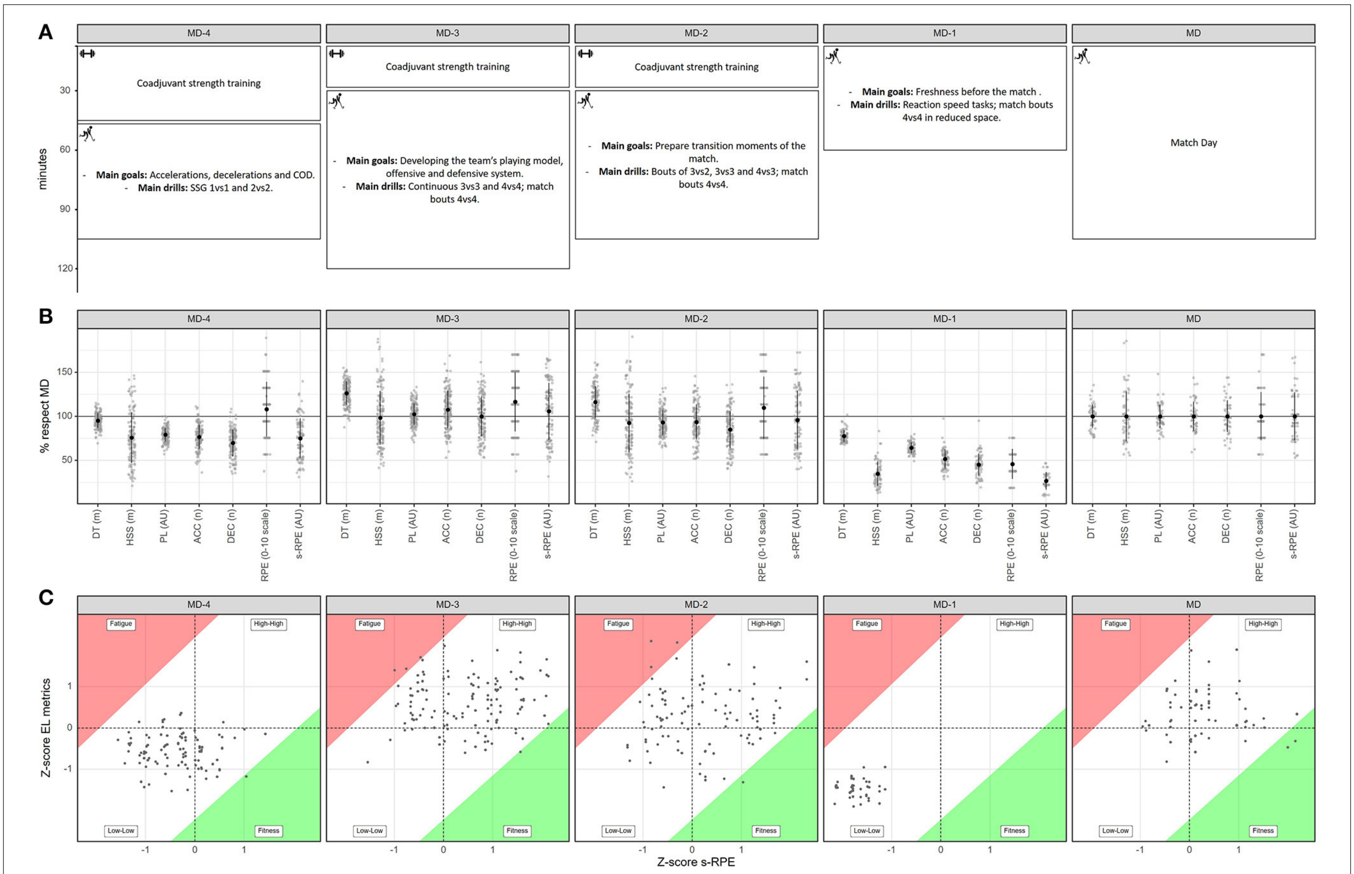

FIGURE 1 | Integrative approach overview of a standard microcycle. **(A)** Main goals, characteristics, and training drills used in each session. **(B)** Mean, standard deviation and data distribution of each session expressed as a percentage of match values. **(C)** Distribution of the mean of the EL metrics *z*-scores (EL metrics *z*-scores) and the IL s-RPE *z*-scores of pooled data from all sessions. DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; RPE, Declared rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session; MD, Match Day.

resampling model with 10,000 bootstrap samples and 95% bias-corrected and accelerated method (BCa 95% CI) was used to calculate the CI of *F*-values of repeated-measures ANOVA for each variable and established that the null hypothesis, that there were no differences, was true if one fell within the CI limits (Plonsky, 2015). The same bootstrap CI approach with a simple resampling model was used to evaluate the *post hoc* pairwise comparisons. The mean difference and effect size value was computed and presented as pairwise change. Thresholds for effect size (ES) statistics were (ES < 0.20), trivial; ($0.20 <$ ES < 0.59), small; ($0.60 <$ ES < 1.19), moderate; ($1.20 <$ ES < 1.99), large; and (ES > 2.0), very large (Hopkins et al., 2009). Finally, a bootstrapped Pearson correlation test was conducted to quantify the correlation between s-RPE and all the EL variables. The magnitude of correlation coefficients, according to Hopkins (2016), was considered trivial ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$), almost perfect ($r > 0.9$), or perfect ($r = 1$). All the reported *P*-values were the likelihoods of the absolute effect sizes being observed if the null hypothesis of zero difference was true (Plonsky, 2015).

RESULTS

The EL and IL descriptive results are represented in **Figure 1** and in **Table 1**. The MD-3 training sessions were the ones with the highest values (except the HSS variable, where the MD is the session with the highest values). In addition, **Figure 1** presents an overview of all the microcycle mean values, with descriptive results relative to match values and *z*-score values of EL (presented as the mean of all *z*-score EL variables) and s-RPE metric for each training session; MD-1 sessions were the ones with the lowest relative load values and the lowest EL and IL demands measured in *z*-score values.

The ANOVA results of all the variables studied are presented in **Table 2**, there being significant differences in all the metrics analysed. Finally, the change of each variable in each pairwise comparison between the different MD is represented in **Table 3** in the form of absolute changes (in the respective units) and effect size changes (in Cohen D units). MD-3 were the training sessions most similar to the match, except in DT, ACC, and declared RPE, in which it surpassed the match values; on the other hand, MD-1 were the training sessions with the most significantly lowest

TABLE 1 | Descriptive statistics (mean ± standard deviation) for all variables each match day.

Variables	MD-4	MD-3	MD-2	MD-1	MD
DT (m)	5,289 ± 466	7,035 ± 754	6,463 ± 1,014	4,324 ± 379	5,568 ± 750
HSS (m)	560 ± 212	727 ± 225	683 ± 245	256 ± 103	739 ± 209
PL (a.u.)	26.9 ± 2.70	34.8 ± 4.15	31.6 ± 4.85	21.8 ± 2.10	34.0 ± 4.54
ACC (*n*)	122 ± 22.0	172 ± 33.7	149 ± 31.9	82.4 ± 17.6	160 ± 26.6
DEC (*n*)	99.9 ± 21.7	143 ± 31.9	121 ± 30.1	64.4 ± 18.3	143 ± 25.8
Declared RPE (0–10 scale)	5.71 ± 1.64	6.16 ± 1.78	5.80 ± 1.87	2.43 ± 0.90	5.29 ± 1.45
s-RPE (a.u.)	356 ± 107	501 ± 153	454 ± 158	126 ± 47.3	474 ± 129

DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; RPE, Rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session; MD, Match day.

TABLE 2 | Bootstrap ANOVA results for each variable.

Variable	*F*	Bootstrap*			
		Bias	Std. Error	BCa 95%CI Lower	BCa 95%CI Upper
DT (m)	242	24.1	25.7	185	266.3
HSS (m)	92.4	9.52	12.0	65.1	106.0
PL (a.u.)	229	22.9	23.7	172	251
ACC (*n*)	224	22.0	23.0	167	245
DEC (*n*)	261	25.3	26.6	199	286
Declared RPE (0–10 scale)	70.5	10.2	10.9	45.4	81.1
s-RPE (a.u.)	111	15.8	15.1	80.5	124

*DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High intensity-decelerations; RPE, Rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session. The null hypothesis was rejected if 1 did not fall within BCa 95% CI limits. *Bootstrap results are based on 10,000 bootstrap samples.*

values in all the metrics studied compared to the other training sessions and the match.

The correlation data analysed between EL and IL (s-RPE) are shown in **Figure 2**. There was a large positive correlation with DT and PL variables, moderate with ACC and DEC variables and a small positive correlation with the HSS metric.

DISCUSSION

The aims of this research were (i) to present an integrative approach to the EL and IL dynamics for monitoring the fitness and fatigue status of specific in-court training sessions of an elite rink hockey team for a standard microcycle, (ii) to evaluate the EL and IL differences between all the training sessions and matches, and (iii) to assess the correlation between EL and IL metrics. To the best of our knowledge, this is the first study to carefully describe the EL and IL dynamics of a microcycle of an elite rink hockey team. In this regard, our results revealed an inverted "*U*-shape" load dynamics in which MD-3 and MD-2 were the two training sessions with the greatest EL and IL of the microcycle in comparison with the other sessions and slightly above the match. Finally, and with regard to the association between EL and IL metrics, large and moderate correlations were found between volume-related variables and s-RPE and low correlations were found between high-intensity-related variables and s-RPE.

Integrative Approach to Training Loads

One of the novelties presented by this study was the determination of the EL and IL dynamics during a standard microcycle comprised of two consecutive seasons. **Figure 1** provides a visual overview of a standard microcycle content (**Figure 1A**), training load dynamics (**Figure 1B**) and an integrative approach of EL and IL for player fitness and fatigue status monitoring based on the proposals by Gabbett et al. (2017) and Delaney et al. (2018) (**Figure 1C**).

With regard to load dynamics, our monitoring approach showed that both EL and IL represented an inverted "*U*-shape" curve throughout a standard microcycle (**Figure 1B**). Regarding EL, the inverted "*U*-shape" presented is like other EL dynamics described elsewhere in other team sport microcycles, such as soccer (Akenhead et al., 2016; Los Arcos et al., 2017; Owen et al., 2017; Martín-García et al., 2018). Other research in soccer showed a decrease from MD-4 sessions to MD (Stevens et al., 2017), and finally, Malone et al. (2014), also in soccer, found no differences between MD-4, MD-3, and MD-2 training sessions. This inverted "*U*-shape" curve seems to correspond to a tapering strategy (Martín-García et al., 2018) in which EL decreases as match day approaches. Interestingly, the most notable characteristic of IL dynamics in our study was the difference between the inverted "*U*-shape" of the s-RPE metric (following the same pattern as EL metrics) versus the flat shape described by the declared RPE (0–10 point scale) variable throughout MD-4, MD-3, and MD-2 training sessions (**Figure 1B**). This declared RPE (0–10 point scale) dynamic might be explained by the fact that this variable is a nominal score given by the player that mainly describes mean training intensity (Haddad et al., 2017), while the s-RPE metric takes not only the intensity but also the duration of the session into consideration (Foster et al., 2001). Excepting MD-1, MD-4 is the shortest of the other three types of training days; this is why, when multiplying the declared RPE by time, the s-RPE was lowest in MD-4 training sessions.

TABLE 3 | 95% Confidence interval of absolute change and effect size change between match days.

Pairwise		DT (m)		HSS (m)		PL (a.u.)		ACC (*n*)		DEC (*n*)		Declared RPE (0–10 scale)		s-RPE (a.u.)	
		95CI lwr.	95CI upr.	95CI lwr.	95CI upr.	95CI lwr.	95CI upr.	95CI lwr.	95CI upr.	95CI lwr.	95CI upr.	95CI lwr.	95CI upr.	95CI lwr.	95CI upr.
MD - MD-4	Abs. Δ	**74.6**	**488**	**118**	**246**	**5.93**	**8.47**	**29.9**	**45.5**	**35.9**	**50.9**	−0.91	0.09	**78.9**	**158**
	ES Δ	**0.12**	**0.85**	**0.54**	**1.14**	**1.73**	**2.49**	**1.23**	**1.93**	**1.53**	**2.21**	−0.58	0.05	**0.68**	**1.35**
MD - MD-3	Abs. Δ	**−1,687**	**−1,241**	−48.4	77.5	−2.11	0.60	**−20.5**	**−3.38**	−8.01	8.73	**−1.33**	**−0.36**	−68.0	17.1
	ES Δ	**−2.28**	**−1.57**	−0.23	0.35	−0.50	0.13	**−0.65**	**−0.10**	−0.27	0.27	**−0.82**	**−0.21**	−0.48	0.11
MD - MD-2	Abs. Δ	**−1,141**	**−634**	−6.35	127	**0.97**	**3.80**	**1.91**	**19.1**	**13.4**	**30.2**	−1.04	0.03	−25.5	65.6
	ES Δ	**−1.23**	**−0.66**	−0.04	0.52	**0.19**	**0.79**	**0.06**	**0.62**	**0.45**	**1.03**	−0.60	0.01	−0.18	0.44
MD - MD-1	Abs. Δ	**1,035**	**1,457**	**429**	**546**	**10.9**	**13.5**	**69.7**	**85.5**	**70.9**	**86.6**	**2.42**	**3.35**	**313**	**386**
	ES Δ	**1.68**	**2.66**	**2.52**	**3.53**	**2.89**	**4.14**	**2.79**	**4.11**	**2.89**	**4.10**	**1.86**	**2.68**	**2.81**	**3.86**
MD-4 - MD-3	Abs. Δ	**−1,878**	**−1,606**	**−217**	**−117**	**−8.71**	**−7.14**	**−56.2**	**−43.5**	**−49.4**	**−37.1**	−0.89	0.01	**−179**	**−111**
	ES Δ	**−3.05**	**−2.41**	**−0.98**	**−0.53**	**−2.48**	**−1.92**	**−1.96**	**−1.46**	**−1.79**	**−1.31**	−0.52	0.00	**−1.36**	**−0.81**
MD-4 - MD-2	Abs. Δ	**−1,356**	**−989**	**−175**	**−68.0**	**−5.72**	**−3.92**	**−33.5**	**−20.6**	**−27.7**	**−15.4**	−0.58	0.39	**−136**	**−61.8**
	ES Δ	**−1.75**	**−1.21**	**−0.76**	**−0.30**	**−1.45**	**−0.98**	**−1.22**	**−0.74**	**−1.06**	**−0.57**	−0.33	0.24	**−1.01**	**−0.46**
MD-4 - MD-1	Abs. Δ	**838**	**1,071**	**262**	**346**	**4.31**	**5.68**	**34.5**	**45.3**	**29.9**	**40.9**	**2.86**	**3.71**	**205**	**256**
	ES Δ	**1.79**	**2.57**	**1.41**	**1.92**	**1.64**	**2.29**	**1.54**	**2.29**	**1.36**	**2.06**	**1.86**	**2.60**	**2.10**	**2.81**
MD-3 - MD-2	Abs. Δ	**362**	**769**	−9.03	97.7	**2.12**	**4.12**	**15.3**	**29.8**	**14.6**	**28.3**	−0.13	0.83	**4.78**	**85.9**
	ES Δ	**0.41**	**0.88**	−0.04	0.42	**0.45**	**0.94**	**0.45**	**0.91**	**0.46**	**0.92**	−0.07	0.46	**0.03**	**0.57**
MD-3 - MD-1	Abs. Δ	**2,556**	**2,843**	**430**	**512**	**12.1**	**13.7**	**82.9**	**96.0**	**72.1**	**84.9**	**3.30**	**4.14**	**343**	**404**
	ES Δ	**3.61**	**4.54**	**2.13**	**2.66**	**3.14**	**3.91**	**2.64**	**3.37**	**2.42**	**3.10**	**1.97**	**2.63**	**2.45**	**3.10**
MD-2 - MD-1	Abs. Δ	**1,954**	**2,328**	**380**	**474**	**8.89**	**10.7**	**60.4**	**73.6**	**50.6**	**63.5**	**2.91**	**3.84**	**294**	**363**
	ES Δ	**2.17**	**2.85**	**1.78**	**2.32**	**2.08**	**2.66**	**2.05**	**2.74**	**1.81**	**2.45**	**1.73**	**2.34**	**2.13**	**2.72**

The confidence intervals are based on the BCa method and 10,000 bootstrap samples. Significant differences ($p < 0.05$) are displayed in bold.
DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; RPE, Rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session; MD, Match Day; CI, Confidence interval; ES, Effect Size; lwr, lower; upr, upper.

Finally, **Figure 1C** presents the IL and EL metrics merged into an integrated system using pooled data *z*-scores; this type of load monitoring approach, based on Gabbett et al. (2017) and Delaney et al. (2018), provides a monitoring tool that places the players in the fitness-fatigue continuum throughout the different microcycle sessions without using tests. This approach uses the relationship between IL and EL metrics in attempt to detect uncoupling between metrics, in other words, attempt to detect when a given EL had a lower (fitness) or greater (fatigue) IL response. Moreover, the use of pooled data helps the observer to see the type of training session and its dispersion with respect to the others, and the quadrant in which it is located intra and inter sessions. In this regard, **Figure 1C** shows that MD-4 and MD-1 sessions tend to place, with low dispersion, the players in a "low EL and IL" zone, guaranteeing a recovery process, especially if combined with an optimal well-being status (Gabbett et al., 2017). On the contrary, in MD-3 and MD-2 sessions, as well as in MD, in which higher loads were recorded, most of the players were placed in a "high EL and IL" zone with a tendency towards dispersion towards the fitness or fatigue zones. This indicates that when players are exposed to high loads, and although most of them will exhibit an expected outcome response ("high El and IL"), the chances of having an unexpected response that would represent an improved fitness status or a fatigue process might be increased. Although this is beyond the scope of this study, such individual unexpected responses (fitness and fatigue) merit further attention in order to individualise the training process better by adjusting training loads and modifying training content.

Differences Between Sessions in the Microcycle

The second aim of this study allowed us to compare training sessions and match EL and IL. One of the main findings was that in the MD-4 training sessions, all EL variables and s-RPE were below the match and MD-3 and MD-2 training sessions, but declared RPE was not different from the match and MD-3 and MD-2 training sessions. The differences in IL metrics (s-RPE vs. declared RPE), as previously stated, can be explained by the difference in definition of the metrics: a nominal intensity score reported by declared RPE versus the inclusion of the duration of the session in s-RPE. Moreover, this specific difference in MD-4 sessions and the rest of the sessions might also be accounted for by the fact that the players were exposed to the longest weekly (45 min) coadjuvant strength training (Gómez et al., 2019) at the gym followed by in-court sessions focusing on SSG (**Figure 1A**). Therefore, coadjuvant strength training in the gym just before the beginning of the specific training session could have had an impact on the declared RPE measured. This content training arrangement has been defined as concurrent training (Fyfe et al., 2014), which might have an effect on EL variables of the specific in-court part of the session (lowering the load) and an effect

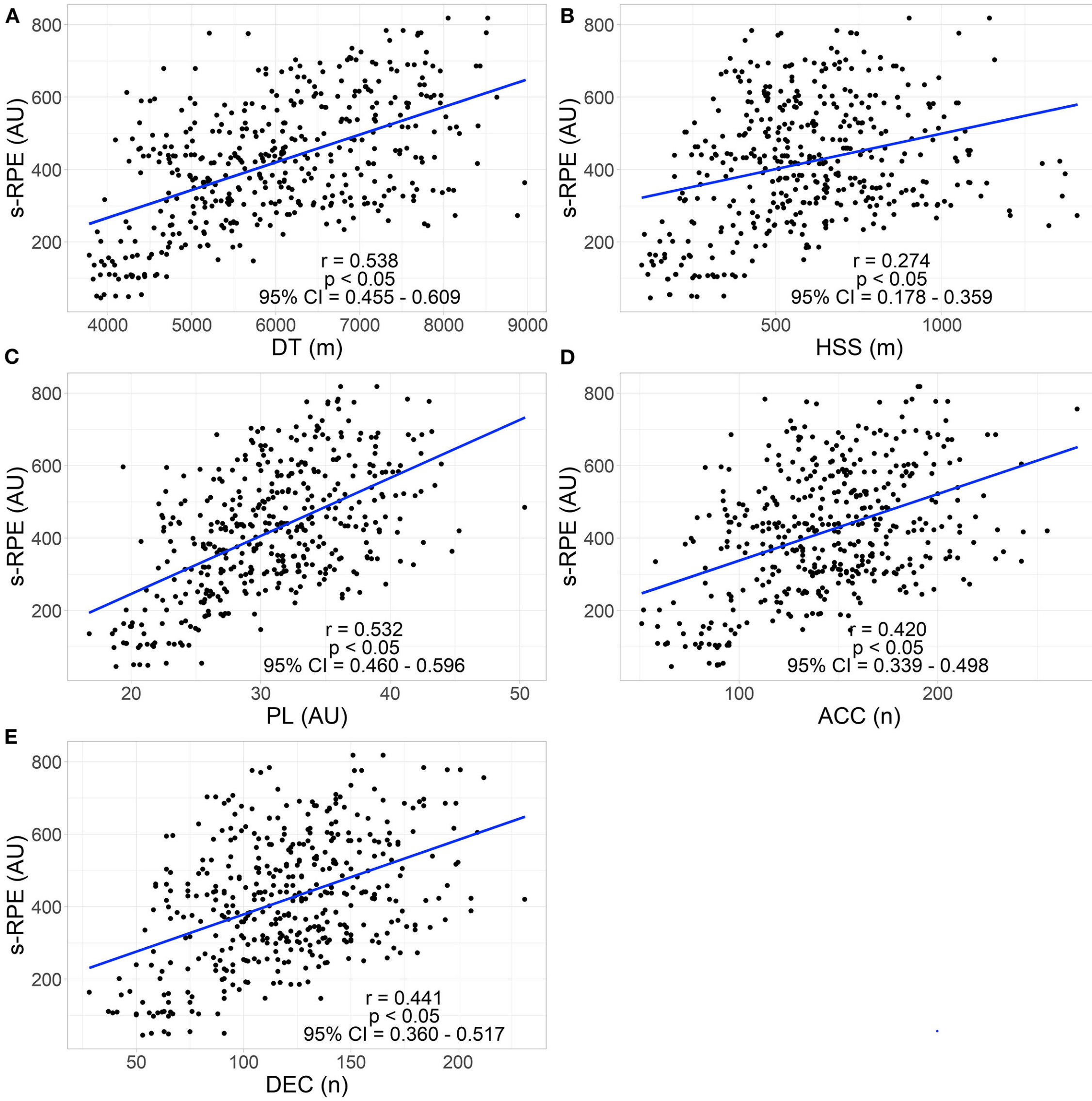

FIGURE 2 | Correlation between EL metrics and session RPE (s-RPE). **(A)** s-RPE and distance travelled. **(B)** s-RPE and high-speed skating distance. **(C)** s-RPE and Player Load. **(D)** s-RPE and number of high-intensity accelerations. **(E)** s-RPE and number of high-intensity decelerations. DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; s-RPE, Rate of perceived exertion × total duration of session.

on the declared RPE (increasing the load), but not on the s-RPE because of the shortert in-court training time. In line with our results, Enright (2014) showed that in soccer, when resistance training was performed before specific soccer training, the specific training declared RPE was significantly higher than the inverse training sequence. Although several mechanisms may account for the difference between IL variables, none of them alone can definitely justify the results. However, knowing the reality of IL and EL dynamics can help staff members to take decisions to optimise MD-4 sessions loads, for example in this specific scenario, separating the strength session from the in-court session (into morning—afternoon sessions) would allow for a greater recovery between sessions that would mean that the perception of effort of the first session did not excessively affect the second one.

Another relevant finding regarding MD comparison was that MD-3 and MD-2 training sessions presented the greatest load demands compared to MD. MD-3 training sessions were superior in DT, ACC, and declared RPE, although no significant differences were found between HSS, PL, DEC, and s-RPE compared to MD; MD-2 sessions were significantly superior in DT; equal in HSS, declared RPE and s-RPE and significantly lower in PL, ACC, and DEC with regard to MD (**Table 3**). These results were similar to those reported by Illa et al. (2020) in futsal, where EL was equal to or greater than MD in the central part of the microcycle but different to outdoor team sports, such as soccer (Stevens et al., 2017; Martín-García et al., 2018), where it proved impossible to reach MD levels in the training sessions and especially in MD-2 training sessions. Unlike indoor team sports, more time may be required to recover from intense pre-match training sessions in outdoor team sports, and for this reason most of the training load was prescribed between MD-4 and MD-3 sessions. The training contents prescribed in MD-3 and MD-2 training sessions described in **Figure 1A** could explain the greater load demands in EL and IL (in some metrics); in line with this, some research in basketball (Vazquez Guerrero et al., 2018) suggests that the bigger the space used in specific in-court drills the greater the EL imposed upon the players. The use of roller skates in rink hockey makes it easy to move around the court and more difficult to remain motionless in one place, and this could be a reason for the higher absolute values of distance, and high-speed distance than in other indoor sports (Fernández et al., 2020b). Another interesting point is that DEC is a variable that is always lower on training days than on the match days (or at most equal). The main point is that, as mentioned in the introduction, DEC in rink hockey may be the variable that makes a difference; for example, when a player returns from an attacking phase to a defensive phase an intense and short deceleration may make the difference between a good defensive transition (timely, fast, and effective) and a bad one (late and tactically un—successful). Finally, as described in **Figure 1C**, all EL and IL metrics (based on the s-RPE metric) presented a major dispersion in MD-3 and MD-2 sessions, albeit with a tendency to be in the "high EL and high IL" quadrant, particularly MD-3 sessions.

Finally, with regard to MD comparison, it is also interesting to emphasise that there was a decrease in all the variables studied as match day approached (MD-1 sessions). The consistent finding of a reduction in MD-1 training sessions of EL and IL denotes a tapering strategy to guarantee freshness before competition. Many studies in team sports have demonstrated that this strategy is effective in ensuring that players will be totally competition-fit (Akenhead et al., 2016; Los Arcos et al., 2017; Owen et al., 2017; Martín-García et al., 2018; Illa et al., 2020). More specifically, if we examine competitive match loads in the weekly load dynamic, considering them as an important factor that conditions the other training sessions (Tarragó et al., 2019); then the MD-1 sessions tapering strategy in team sports consists of lowering EL and IL, ensuring recovery and guaranteeing players' match readiness (Svilar et al., 2019). In summary, and as described in **Figure 1C**, MD-1 presented a "low EL and low IL" profile with a low data dispersion, ensuring a consistent tapering strategy in the team analysed.

Correlation Between EL and IL

The third and final objective of this research was to examine the correlations between EL and IL. The analysis of the relationship between the EL variables studied and the s-RPE IL metric is presented in the **Figure 2**. The correlations studied in the team analysed ranged from high to low in all the metrics selected; DT and PL were the two variables with the highest values of correlation with s-RPE with high values; HSS was the lowest correlated variable with s-RPE with low results. The volume metrics (DT and PL) findings are in line with those of Scanlan et al. (2014) in basketball, who found that the relationship between accelerometer training load data (similar to PL metric) and s-RPE was very similar to the correlation of our research. In contrast, field-based team sports presented stronger relationships between volume EL metrics and IL (Burgess et al., 2006; Scott et al., 2013) than indoor team sports. On the other hand, high-intensity metrics such as HSS presented the lowest correlation with IL, suggesting, on the one hand, and in line with Fernández et al. (2020b), that high-speed movement may be maintained through the use of inertia from a previous effort and not through the player's continual effort, whereby the HSS metric does not account for the players' entire internal response; and on the other hand, in line with Scott et al. (2013), that as the speed of EL criterion increases (the HSS threshold was 18 $km \cdot h^{-1}$), the strength of its relationship with s-RPE becomes weaker. Modern rink hockey is based on a very high pace of skating and of ball possession (Perez, 2017). In addition, professional teams seek faster offensive and defensive transitions, which probably increases the HSS volume per match as in soccer, where high—speed running distances have increased in recent years (Bush et al., 2015). This suggests the need for more research into HSS and its degree of correlation with IL and also, into absolute and relative thresholds in HSS. Finally, the results of the correlation analysed suggest that not only do EL variables affect IL response, but also that individual characteristics, psychological status, health, nutrition and the environment, among other intrinsic and extrinsic factors, could affect this response (Impellizzeri et al., 2019). Therefore, taking the different degree of association between EL and IL metrics (ranging from high-to-moderate for volume EL metrics and s-RPE and moderate-to-low for intensity EL metrics and s-RPE) into account, both variables should be measured, since they offer complementary information about conditional demands and elite rink hockey players' response to these demands, respectively.

CONCLUSIONS

This research, the first of its kind with an elite rink hockey team, presents an integrative approach to the EL and IL of players for monitoring fitness and fatigue status during a standard microcycle. As a skating sport, DEC in rink hockey could be the variable that make a difference in match situations, possibly being this the reason why DEC was the only (along with HSS) EL variable that did not surpass the match volume during a standard microcycle. An inverted "*U*-shape" load dynamics with a load peak between MD-3 and MD-2 sessions, a mismatch between declared RPE and s-RPE metric in MD-4 sessions and a high correlation between volume EL variables and IL (s-RPE) were the most important findings in this team's microcycle. This could provide team sport staff members (coaches, strength and conditioning coaches, and physicians) with a deeper understanding of load distribution throughout the microcycle. The use of *z*-scores analyses integrating EL and IL builds up an objective decision-support tool for changing and adapting training loads and content. This study is based on a single elite rink hockey team with international top-level players, and the findings provide a basis for the quantification of a standard microcycle, constituting a point of departure for other research into EL and IL in this sport as well as in other team sports.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the ethics committee for clinical research of the Catalan Sports Council 29/CEICGC/2020. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DF participated in the design of the study, contributed to data collection, reduction, analysis, interpretation of results, and contributed to the manuscript writing. DM participated in the interpretation of results and contributed to the manuscript writing. JC contributed to the manuscript writing. GC participated in the design of the study, contributed to interpretation of results, and manuscript writing. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

FUNDING

This study was supported by the Institut Nacional d'Educació Física de Catalunya (INEFC).

ACKNOWLEDGMENTS

The authors gratefully acknowledge to all elite players who participated in the study. The authors gratefully acknowledge the Institut Nacional d'Educació Física de Catalunya (INEFC) for their collaboration in this study. The authors also would like to thank all the members of the Sports Performance Area of FC Barcelona for their valuable contribution to this study, as well as the support of the Barça Innovation Hub.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Sports and Active Living

BRIEF RESEARCH REPORT
published: 15 July 2021
doi: 10.3389/fspor.2021.680799

Post-match Recovery Practices in Professional Football: Design, Validity, and Reliability of a New Questionnaire

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OPEN ACCESS

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Sports and Active Living

Received: 15 March 2021
Accepted: 03 June 2021
Published: 15 July 2021

Citation:
Querido SM, Brito J, Figueiredo P, Carnide F, Vaz JR and Freitas SR (2021) Post-match Recovery Practices in Professional Football: Design, Validity, and Reliability of a New Questionnaire. Front. Sports Act. Living 3:680799. doi: 10.3389/fspor.2021.680799

Introduction: Although several approaches have been proposed to mitigate post-match fatigue, few studies have been conducted in team sports to understand the types of recovery methods and the underlying reasons for the choices of medical and technical staff. This study aimed to develop a valid and reliable online questionnaire to assess the recovery practices implemented by football clubs within 72 h post-match.

Methods: Two research members developed the original questionnaire proposal, and two experts in sports science and sports medicine confirmed the content and face validities. Then, 20 football coaches (age: 39.4 ± 6.8 years) with a minimum of 5 years of experience in professional football (9.1 ± 4.9 years) and with an academic background participated in determining the ecological validity and reliability of the questionnaire. The acceptability and relevance of the questionnaire were determined using descriptive statistics.

Results: After confirming the content and face validities, one questionnaire section with two questions was excluded due to lack of relevance, seven open-ended questions were removed due to the adherence of small participants (i.e., 45.4%), and one section was divided into three to facilitate clearness in reading. The remaining sections were considered acceptable and relevant (>94.1%). About 91.8% of nominal and ordinal items derived from the questionnaire questions showed good to very good reliability outcomes (average *k* classification: 0.73 ± 0.13; min–max: 0.22–1.00, $p < 0.05$; average *wk* classification: 0.82 ± 0.15; min–max: 0.22–1.00, $p < 0.05$).

Conclusions: This study provided a novel, valid, reliable, and easy-to-use tool to examine the post-match recovery practices in professional football contexts.

Keywords: fatigue, recovery assessment, survey, validation, soccer

INTRODUCTION

Optimal recovery is fundamental to avoid long-term fatigue and adverse consequences such as under-recovery, non-functional overreaching, or overtraining syndrome (Doeven et al., 2018; Kellmann et al., 2018). This is particularly important in professional sports contexts, where the density of competitions may be high. Several approaches have been proposed to mitigate the post-match effects on physical impairments and to increase recovery kinetics (Nédélec et al., 2013; Abaidia and Dupont, 2018; Altarriba-Bartes et al., 2020b). However, different recovery methods have distinct degrees of effectiveness. For instance, Nédélec et al. (2013), Machado et al. (2016), and Abaidia and Dupont (2018) reported that hydration, adequate nutrition, adequate sleep routines, and the use of cold water immersion at 9–10°C for 10–20 min allow a reduction in muscle soreness and accelerate the recovery process. These practices appeared to shorten the recovery time in terms of restoring the initial level of performance, resulting in early readiness. Despite the improvements shown in perceptual ratings after the use of cold modalities, limited evidence exists regarding cooling effects on any other objective parameter, such as lactate levels, CK levels, IL-6 levels, or muscle strength, during a 96-h recovery period (Torres et al., 2012; Hohenauer et al., 2015). Similarly, the evidence that supports the effectiveness of active recovery, stretching, compression garments, massage, and electrical stimulation in professional teams is scarce (Nédélec et al., 2013). This creates difficulties among professionals when selecting the best recovery approaches for athletes.

The recovery practices used by professional football teams have been scarcely studied (Nédélec et al., 2013; Altarriba-Bartes et al., 2020b). To our knowledge, only three studies have been conducted in team sports to understand the types of recovery strategies and the underlying reasons for the choices of medical and technical staff (Van Wyk and Lambert, 2009; Nédélec et al., 2013; Altarriba-Bartes et al., 2020a). Taking everything into account, studies provided insights into the usage of recovery methods in high-performance team sports but did not specify the periods in which they should be used after competitions. It is important to note that the choice of recovery methods may be sport-dependent due to the sports-specific physiological demands. Likewise, the choice of recovery methods may also depend on the institutional socioeconomic context (Hoffmann et al., 2002). Therefore, it is important to characterize the recovery modalities in different sports and in different countries. Moreover, three studies have investigated the perception of an athlete regarding recovery practices and the effectiveness of several recovery modalities commonly used in team sports (Venter, 2014; Crowther et al., 2017; Tavares et al., 2017). However, the questionnaire has been directed to athletes who did not provide information underlying the decision-making. In addition, the aforementioned studies provided a generic view of recovery practices adopted but not in specific moments such as after competitions where the physiological and psychological demands are higher as compared to the training contexts (Nédélec et al., 2012; Silva et al., 2018).

As the accuracy of the given information is highly dependent on the validity and reliability of the data collection instrument (Hopkins, 1998; Leppink and Pérez-Fuster, 2017), it is important to first determine how well the new tool measures the underlying construct. Hopkins (1998) emphasized the point that questionnaires *per se* are not reliable and that research instruments lacking reliability cannot measure any variable better than chance alone.

This study aimed to develop and validate an online questionnaire to assess the recovery practices implemented in elite football within 72 h post-match. A high level of agreement between raters and high reliability was expected to be observed so that confidence could be obtained to use the questionnaire in future studies.

METHODS

Study Design

The research project was divided into three phases. In phase I, online questionnaire content was developed. In phase II, the content and ecological validities of the questionnaire were determined. Finally, in phase III, the reliability of the questionnaire was determined.

Participants

Two sports science researchers, with at least 5 years of experience with recovery methods in elite football, built the first proposal of the questionnaire (phase I). Subsequently, two professional experts in sports science (Ph.D. in Sports Science) and sports medicine (specialization in Sports Medicine), both with more than 10 years of experience in practice and research on recovery methods in professional football, were invited to participate in the content validity and face validity procedure (phase II). In addition, 20 Portuguese football coaches (age: 39.38 ± 6.79 years) with a minimum of 5 years of experience in professional football (i.e., 9.07 ± 4.92 years) and at least a bachelor degree were invited to participate in the questionnaire ecological validity (i.e., acceptability and relevance) procedure (phase II). The sample size for validation of the pre-test questionnaire was chosen considering a sample of 15 to 20 participants, as previously recommended (Sheatsley, 1983; Vieira, 2009; Perneger et al., 2015). Regarding the recommendation, a sample of 20 professionals that is sufficient to detect at least the occurrence of one problem with a statistical power of 90% in a prevalence of the problem of 0.11 has been proposed (Perneger et al., 2015). The same coaches who participated in phase II were also invited to participate in the reliability procedure of the questionnaire (phase III). The participants were invited by personal contact and/or by email contact between April 2019 and July 2019. This study was approved by the local ethics committee (approval number: 10/2019), and the procedures were conducted according to the principles expressed in the Declaration of Helsinki. All participants gave their written informed consent to participate in this study.

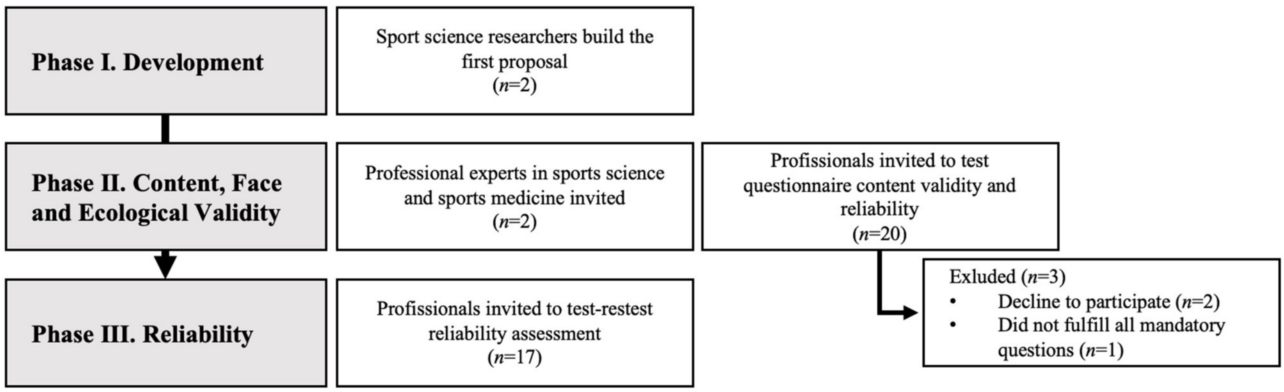

FIGURE 1 | Flow diagram of sample attendance and questionnaire validation procedures.

Procedures

This questionnaire was developed to be applied to the professionals responsible for the post-match recovery approaches in Portuguese professional football teams. It was assumed that these professionals hold an academic degree in the following: sports coaching, sports science, physical therapy, or sports medicine. The study phases and the sample attendance are shown in **Figure 1**.

In phase I (i.e., development), two researchers conceived the proposal of the original questionnaire based on the previous findings (Nédélec et al., 2013; Johnston et al., 2015; Owen et al., 2015). This procedure was used to define the construct of the questionnaire as no previous instrument has been conceived for a similar purpose. The questionnaire was written in Portuguese language and inserted in an online survey platform (LimeSurvey Open-Source platform, v3.17.9, LimeSurvey GmbH, Hamburg, Germany) to be filled online while assuring anonymity. In addition to the informed consent and personal information sections, questions were developed with the objective to (i) examine the importance given to the recovery intervention after the match and (ii) to characterize the type and extent of recovery method used at different post-match moments until 72 h after home and away matches. Closed-ended questions with nominal (variables with categories that do not have a natural order or ranking) and ordinal measurement scales (variables that have a natural order or ranking) and open-ended questions were considered. Closed-ended questions were designed through dichotomous and Likert scales with five categories.

In phase II, for the examination of content and face validities, two sports science and sports medicine experts commented on the initial proposal and proposed changes concerning whether the questionnaire contents were understandable and achieved the purpose of the questionnaire (Bolarinwa, 2015). Based on those comments, changes were made in the initial questionnaire by removing questions, changing their content, and altering the sequence of questions. To ensure the questionnaire was acceptable and relevant in an ecological setting (i.e., ecological validity), the invited professional football coaches completed the questionnaire and added some comments when justified. Based on those comments, changes were introduced in the questionnaire by removing questions that were not understandable and/or not considered relevant for the study purpose. Unanswered open-ended questions were removed (Vieira, 2009). The final version of the questionnaire was obtained at the end of phase II. After 7 days, the same professional football coaches who participated in ecological validation were asked to fulfill the questionnaire once again and, consequently, participated in test–retest questionnaire reliability (i.e., phase III).

Data Analysis

Data analysis was performed using IBM SPSS Statistics (v26, IBM Corporation, New York, USA). Descriptive statistics were conducted to characterize the sample and to examine the acceptability and relevance of the questionnaire. Mean and SD were calculated for continuous variables, and absolute and relative frequencies were determined for nominal variables. Reliability testing was performed by calculating Cohen's kappa coefficient (k) and weighted Cohen's kappa coefficient (wk) for nominal and ordinal variables, respectively. The k and wk were classified as poor ($<$0.20), fair (0.20–0.39), moderate (0.40–0.59), good (0.60–0.79), and very good (0.80–1.00) (Landis et al., 1977).

RESULTS

A questionnaire with 34 questions, organized in five sections, was obtained in phase I (**Supplementary File 1**). The first two sections (i.e., five closed-ended questions and one open-ended question) were designed for informed consent and for the purpose of characterization of participants. Section Results (i.e., Portuguese language: reconhecimento da importância das práticas; English translation: recognition of the importance of practice) resulted in two closed-ended questions. Section Discussion (i.e., Portuguese language: caracterização das práticas; English translation: characterization of the practices) resulted in 11 closed-ended and 11 open-ended questions. Section Data Availability Statement (i.e., Portuguese language: o treino como estratégia preventiva; English translation: training as a preventive

TABLE 1 | The number of positive responses among the participants ($n = 17$) concerning the acceptability, relevance, and suggestions of questionnaire sections during the ecological validation process.

Questionnaire Section	Acceptability *n* (%)	Relevance *n* (%)	Suggestions *n* (%)
1. *Consentimento* (Informed consent)	17 (100.0)	17 (100.0)	0 (0.0)
2. *Informações pessoais* (Personal details)	17 (100.0)	17 (100.0)	0 (0.0)
3. *Reconhecimento da importância das práticas* (Recognition of the importance of practices)	16 (94.1)	16 (94.1)	1 (5.9)
4. *Caracterização das práticas* (Characterization of the practices)	17 (100.0)	17 (100.0)	0 (0.0)

n, number of responses.

strategy) resulted in one closed-ended question and one open-ended question.

In phase II, based on the comments from experts, the questionnaire had the following changes: One section (with one closed-ended question and one open-ended question) was excluded due to lack of relevance; section Discussion (i.e., "caracterização das práticas"; characterization of the practices) was divided into three sections to facilitate the clearness in reading; and eight questions were modified to facilitate understanding. In addition, face validity was guaranteed for all items of the questionnaire. During the ecological validation (phase II) and reliability testing (phase III) processes, three participants were excluded (i.e., two did not accept the initial invitation, and one did not fulfill all mandatory questions); thus, only 17 participants accomplished all the steps. The acceptability and relevance outcomes are presented in **Table 1**.

Questionnaire sections were considered acceptable and relevant by most of the participants (i.e., >94.1%). One participant did not accept and considered two questions of section Results as relevant (i.e., items C2 and C4) and suggested small changes related to the text format and instructions. The corrections suggested in the two items were implemented to facilitate the clearness in reading. In addition, seven open-ended questions were removed due to the adherence of small participants (i.e., 45.4%). A final questionnaire version comprising 19 questions separated into six sections was obtained (**Supplementary File 2**). From the reliability procedure of phase III, 91.8% of nominal and ordinal items derived from the questions of the questionnaire showed good to very good reliability outcomes (**Table 2**).

For nominal items, first, in section Results (average k classification: 0.71 ± 0.21; range: 0.35–1.00, $p < 0.01$), one item showed a fair classification, one showed a moderate classification, four showed a good classification, and three showed a very good classification. Second, in section Discussion (average k classification: 0.79 ± 0.13; range: 0.63–1.00, $p < 0.05$), six items showed a good classification and five showed a very good classification. Finally, in section Data Availability Statement (average k classification: 0.54 ± 0.45; range: 0.22–1.00, $p < 0.01$), one item showed a fair classification, and one item showed a very good classification. For ordinal items, first, in section Results (average wk classification: 0.68 ± 0.22; range: 0.22–1.00, $p < 0.01$), one item showed a fair classification, five showed a good classification, and three showed a very good classification. Second, in section Discussion (average k classification: 0.82 ± 0.14; range: 0.46–1.00, $p < 0.05$), 3 items showed a moderate classification, 5 showed a good classification, and 19 showed a very good classification. Finally, in section Data Availability Statement (average k classification: 0.85 ± 0.11; range: 0.63–1.00, $p < 0.01$), 9 items showed a good classification and 18 items showed a very good classification.

DISCUSSION

This study aimed to develop a valid and reliable online questionnaire for the assessment of recovery practices implemented in elite football within 72 h post-match. A high level of agreement between raters and high reliability was obtained.

To our knowledge, only three studies have assessed recovery methods implemented by support sports staff in team sports through a questionnaire (Van Wyk and Lambert, 2009; Nédélec et al., 2013; Altarriba-Bartes et al., 2020a). Although good scientific contribution can be obtained from the aforementioned studies, we contend that some fundamental methodological aspects were disregarded. For instance, Van Wyk and Lambert (2009) determined the content validity by applying the proposed questionnaire in two moments for two different groups of individuals, which were reported to have similar characteristics to the target sample of the study. Although the characteristics were not mentioned, the comparison might have been affected, as individuals who evaluated the questionnaire were not the same. In contrast, Altarriba-Bartes et al. (2020a) ensured similar characteristics by applying a pilot test of the survey to two semiprofessional teams that were not included in the study. Similarly, Dadebo et al. (2004) conducted a survey to examine the relationship between stretching practices and hamstring injuries in English professional football. To ensure similar characteristics to the target sample, during the content validity process, the questionnaire was piloted by the responsible persons of three professional clubs, picked previously from the same study sample. In this study, content validity was confirmed doubly (i) by sports science/medicine experts and (ii) by football coaches with experience in the same football context and academic background. Moreover, first, in contrast to the previous studies, face validity was guaranteed by sports science/medicine experts following the procedures of Bolarinwa (2015).

Second, compliance with the questionnaire was not reported. In this study, acceptability and relevance were measured to ensure that the contents of the questionnaire were in line with

TABLE 2 | Reliability outcomes for nominal and ordinal items derived from the questions of the questionnaire.

Section 3			Section 4			Section 5		
Item	**Cohen's *k* (k)**	**Classification**	**Item**	**Cohen's *k* (k)**	**Classification**	**Item**	**Cohen's *k* (k)**	**Classification**
Nominal items								
C2a	1.00	Very Good	D1	1.00	Very Good	D17	0.85	Very Good
C2b	0.70	Good	D3a	0.79	Good	D19	0.22	Fair
C2c	0.81	Very Good	D3b	0.71	Good			
C2d	0.66	Good	D3c	0.71	Good			
C2e	0.72	Good	D3d	0.64	Good			
C2f	0.55	Moderate	D3e	0.63	Good			
C2g	0.63	Good	D3f	0.89	Very Good			
C2h	0.35	Fair	D3g	0.82	Very Good			
C2i	1.00	Very Good	D3h	0.81	Very Good			
			D3i	1.00	Very Good			
			D8	0.71	Good			

Section 3			Section 4			Section 5		
Item	**Cohen's *k* (wk)**	**Classification**	**Item**	**Cohen's *k* (wk)**	**Classification**	**Item**	**Cohen's *k* (wk)**	**Classification**
Ordinal items								
C1	0.60	Good	D6a	0.83	Very Good	D17	0.85	Very Good
C4a	0.70	Good	D6b	0.90	Very Good	D19	0.22	Fair
C4b	0,72	Good	D6c	0.92	Very Good	D15a	0.78	Good
C4c	0.70	Good	D6d	0.81	Very Good	D15b	0.81	Very Good
C4d	0.81	Very Good	D6e	0.78	Good	D15c	0.86	Very Good
C4e	0.84	Very Good	D6f	0.91	Very Good	D15d	0.85	Very Good
C4f	0.49	Good	D6g	0.57	Moderate	D15e	0.92	Very Good
C4g	0.22	Fair	D6h	0.46	Moderate	D15f	0.96	Very Good
C4h	1.0	Very Good	D6i	0.88	Very Good	D15g	0.87	Very Good
			D10a	0.83	Very Good	D15h	1.00	Very Good
			D10b	1.00	Very Good	D15i	0.84	Very Good
			D10c	0.94	Very Good	D21a	0.76	Good
			D10d	0.94	Very Good	D21b	1.00	Very Good
			D10e	0.90	Very Good	D21c	0.73	Good
			D10f	0.89	Very Good	D21d	0.75	Good
			D10g	0.89	Very Good	D21e	0.95	Very Good
			D10h	0.63	Good	D21f	0.95	Very Good
			D10i	1.00	Very Good	D21g	0.72	Good
			D12a	0.64	Good	D21h	0.63	Good
			D12b	0.92	Very Good			
			D12c	0.85	Very Good			
			D12d	0.77	Good			
			D12e	0.89	Very Good			
			D12f	0.89	Very Good			
			D12g	0.74	Good			
			D12h	0.81	Very Good			
			D12i	0.57	Moderate			

k, Cohen's kappa coefficient; wk, weighted Cohen's kappa coefficient.

the final purpose. Finally, the reliability of the questionnaires was not reported. As reliability reflects the repeatability of scores and the consistency over time (Hopkins, 1998; Leppink and Pérez-Fuster, 2017), it is very important to confirm where the instrument ensures a stable and representative response of participants over time. Thus, the present questionnaire provides accurate outcomes in terms of recovery practices in the post-match context of professional football.

In consequence of the demanding process of development, validation, and reliability processes, the present questionnaire presents some specific characteristics that define its context of use and increase the probability of its effectiveness. For instance, only closed-ended questions were included in the questionnaire, which is contrary to the studies proposed by Van Wyk and Lambert (2009) and Altarriba-Bartes et al. (2020a). On the one hand, open-ended questions allow responders to include more information about the subject, but, on the other hand, it can lead to a lot of noise that can make difficult the deep understanding behind the issue. We decided to remove open-ended questions due to the adherence of small participants, despite the known high reliability in these types of questions (Krosnick, 2018). In addition, questions with low response rates during a pre-test should be removed in the post-test (Vieira, 2009). In the same line, a response rate lower than 70% has been recommended as a cutoff to define whether questions should be removed (Dillman et al., 1974; Fan and Yan, 2010), which was adopted in this study. Additionally, based on the response of the participants during the validity process, the content of some questions was also modified in order to facilitate the clearness in reading. Section Discussion was also divided into three different sections based on the recommendations of Fan and Yan (2010), which reported that the layout design (i.e., screen-by-screen or scrolling layouts), text format for questions, and instructions significantly influenced the response rate. Moreover, in Likert-related questions, care was taken to have more than four options of response (Lozano et al., 2008) and with an odd number of options so that responders could choose a neutral response (Streiner et al., 2015). Thus, we have used questions with five options. We believe that all these procedures have contributed to the high reliability observed.

Despite the demanding validation process and high reliability observed, this study had some limitations. The exclusive use of a sample of Portuguese participants does not allow a generalization of the main findings to different contexts worldwide. The questionnaire criterion validity was also not assessed, as it would imply to assess the behaviors of coaches concerning the post-match recovery methods, which was not possible to implement. Additionally, a questionnaire provided in the Portuguese language does not allow further use in the context of different languages without having accomplished similar validity and reliability processes.

An important aspect that should be noted is the observed adhesion of high participants (85.0%). As indicated by Fan and Yan (2010), this may be because questionnaires promoted by academic and governmental agencies usually have higher response rates than those sponsored by commercial ones. Another factor that may contribute to the high adhesion is the intrinsic motivation of participants related to the subject of the questionnaire. Thus, future studies may consider the duration of experience and educational background of participants that may increase the predisposition to adhere to these types of assessments (i.e., questionnaires).

In conclusion, this study provides a novel, valid, reliable, and easy-to-use tool to examine post-match recovery practices in elite football contexts. Although the questionnaire was provided in Portuguese language, it can be used as a basis in other languages after its validation. From a practical perspective, besides the contribution of this tool in future research studies with the provision of accurate information, this study may also contribute to the knowledge of the current practices and methods in post-match recovery in professional football. In addition, this study may also help to clarify some divergences between theory (i.e., the effectiveness of methods) and practice (i.e., methods used) as shown in post-match recovery in professional football.

DATA AVAILABILITY STATEMENT

The original contributions generated for the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of University of Lisbon, Faculty of Human Kinetics. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SQ, JB, PF, JV, and SF: conceptualization. SQ, JB, and SF: acquisition of data. SQ, JB, PF, FC, JV, and SF: analysis and interpretation of data and review and editing. SQ: original drafting. JB and SF: supervision. All authors have read and agreed to the published version of the manuscript.

FUNDING

SF and JV are supported by the Fundacao para a Ciencia e a Tecnologia (grant PTDC/ SAU-DES/31497/2017).

ACKNOWLEDGMENTS

The authors thank all the coaches and experts for participating in this study.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2021.680799/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Physiology

MINI REVIEW
published: 03 August 2021
doi: 10.3389/fphys.2021.722550

Potential Role of Cannabidiol on Sports Recovery: A Narrative Review

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The use of cannabidiol (CBD) among athletes is becoming extensive and frequent. This could be due to the elimination of CBD from the list of prohibited substances by federations and international institutions of sport. The legalization and resulting production, and commercialization of CBD, could increase its intake in sports professionals. This commercialization of cannabinoids has fueled a race to study their properties, benefits, and risks for health and performance in athletes. Although there is evidence that suggests some beneficial properties such as anxiolytics, antidepressants, anti-inflammatory, and antioxidants among others, the evidence presented so far is neither clear nor conclusive. There are significant gaps in knowledge of the physiological pathways that explain the role of CBD in sports performance. This mini-review examines evidence suggesting that CBD has the potential to be used as a part of the strategies to recover from fatigue and muscle damage related to physical and cognitive exertion in sports.

Keywords: sport, fatigue, CBD, injury, sleep, exercise

Edited by:
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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *09 June 2021*
Accepted: *09 July 2021*
Published: *03 August 2021*

Citation:
Rojas-Valverde D (2021) Potential Role of Cannabidiol on Sports Recovery: A Narrative Review. Front. Physiol. 12:722550. doi: 10.3389/fphys.2021.722550

INTRODUCTION

Recovery has become a crucial topic in recent sports research and could determine physical (Trecroci et al., 2020b), physiological (Rojas-Valverde et al., 2018), and cognitive (Trecroci et al., 2020a) performance, considering the high frequency and density of competitions. This has led the researchers, coaches, and athletes making plans and managing recovery strategies as part of the general exercise prescription (Martínez-Guardado et al., 2020). The physical, physiological, and cognitive effort usually provoke a cascade of structural and functional adjustments that need to be identified, monitored, and controlled to optimally recover the functional capacities of the athlete (Ament and Verkerke, 2009). Commonly, central and peripheral fatigue related to physical exercise manifests itself as pain, weakness, inflammation, loss of functional mobility, decreased force generation, feeling of tiredness, alteration of vital signs, and reduced concentration, among others.

Over the last few years, many methods and means of recovery from fatigue have been tested (Rawson et al., 2018). One of the best known strategies is the intake of plant-derived products such as ginseng (Rojas-Valverde et al., 2020), green tea (Machado et al., 2018), cherries (Bell et al., 2014), curcumin (Fernández-Lázaro et al., 2020), spinach (Bohlooli et al., 2014), and beetroot (Rojas-Valverde et al., 2020). These organic products have shown anti-inflammatory, antioxidative, and analgesic properties as other cognitive benefits that promote recovery from exercise-related fatigue (Bongiovanni et al., 2020).

Recently, the World Anti-Doping Agency has removed some products from their list of prohibited substances for athletes. This is the case of cannabidiol (CBD), a phytocannabinoid clustered among the cannabinoids extracted from the *Cannabis sativa* plant (Campos et al., 2012). Unlike tetrahydrocannabinol (THC), CBD does not cause psychotomimetic and psychotropic reactions (WHO, 2017) for which there is no evidence of dependence or abuse, but causes mild and infrequent side effects (Stout and Cimino, 2014). On the contrary, CBD use is not only extensive among athletes (Docter et al., 2020), but it has been shown to have specific properties that help to treat chronic pain, spasticity, mood and sleep disorders, immunodepression, inflammation, oxidant effects, and anxiety in clinical patients (McPartland et al., 2015; Whiting et al., 2015; Nichols and Kaplan, 2019; Pinto et al., 2020). These effects could improve and accelerate recovery caused by a prolog or intense physical, physiological, and cognitive efforts as in sports (Higgins et al., 2017).

Considering that CBD has gained wide acceptance for medicinal and recreational use, its use among athletes is imminent (Docter et al., 2020) even though its the physiological, physical, and cognitive effects are not fully understood (Nichols and Kaplan, 2019), and it seems premature to make specific recommendations and to award all the above mentioned benefits (Gamelin et al., 2020). Consequently and considering the need to clarify these issues, this narrative review aims to present the scientific evidence around the potential benefits of CBD as an ergogenic aid to promote a better and faster recovery between efforts related to physical exercise and sport. Given the absence of evidence directly exploring the CBD potential in sports recovery, this review synthesizes the preclinical and clinical findings that support its use and testing in future research protocols. This narrative review was performed considering the scale for assessment of narrative review articles (Baethge et al., 2019).

PREVALENCE IN THE USE OF CBD AMONG ATHLETES

With the exclusion of CBD from the prohibited substances in 2018, and even before, the use of CBD among athletes has considerably increased and is still accelerating (Leas et al., 2019). Cannabinoids are considered the second most commonly used substance among contact sports athletes replacing nicotine (McDuff et al., 2019). Evidence has shown that a third of cyclists, triathletes, and runners are or have been cannabinoids users (mostly $\geq$ 40 years of age, male, THC + CBD consumers $\leq$3 times weekly, and exercise 5–7 days per week) (Zeiger et al., 2019). Also, a quarter of university athletes report using cannabis-related products (Docter et al., 2020). Especially in contact sports like rugby, the use rate of CBD is 28%, increasing with age, and reporting pain relief and sleep quality improvements as perceived benefits (Kasper et al., 2020).

Despite the extensive use of CBD and the fact that international sports organizations have now allowed for it to be used, some CBD products have been shown to contain significant levels of other banned cannabinoids, like THC (Lachenmeier and Diel, 2019). Besides, there is evidence of the use of synthetic cannabinoids, such as JWH-018 and JWH-073, with limited regulation (Heltsley et al., 2012). Athletes require more information and advice, as product labels can be misleading about whether they contain THC, meaning there are risks in terms of violating anti-doping rules (Mareck et al., 2021).

PHYSIOLOGICAL MECHANISM FRAMING CBD

The effects of CBD on physiological and cognitive functions are mediated by the endocannabinoid system, which has regulatory functions to maintain homeostasis (VanDolah et al., 2019). During exercise, the cannabinoid system mediates some central and peripheral effects of exercise as bliss, peacefulness, and euphoria (Carek et al., 2011). Endocannabinoids [e.g., anandamide and 2-arachidonyol (2AG)] as cannabinoids activate the type-1 (CB_1) and type-2 (CB_2) cannabinoid receptors, such as *N*-acylethanolamines (De Petrocellis and Di Marzo, 2009), leading to appetite-suppression, anti-inflammatory, anxiolytic, and antiproliferative effects as exercise do. CBD inhibits the degradation and uptake of endocannabinoids as anandamide, leading to an increase in endocannabinoid–receptor binding. CB_1 and CB_2 are present mostly in the central nervous and peripheric nervous system, respectively.

Also, cannabinoids and endocannabinoids are involved in brain-derived neurotrophic factor release (e.g., neurogenesis and neuronal plasticity), glucocorticoids release (e.g., mood control by suppressing depression and anxiety), dopamine release (leading to rewarding), and fatty acid amide hydrolase release (e.g., analgesic effects). All these responses overlap with the positive benefits of exercise (Tantimonaco et al., 2014). These effects are provoked by stimuli of TRPV1 ions canals (Vanilloid receptors) leading to antinociceptive effects, stimuli of CB_1 and CB_2 receptors causing relaxing effects *via* neurodepression and inhibition of cytokines release, respectively, and activation of $5HT_{1A}$ receptors promoting serotonin caption in the postsynaptic neuron causing mood state regulation.

INFLAMMATION AND PROLIFERATION

Inflammation and oxidative stress underlie many human chronic and acute health conditions and pathologies. In this sense, and considering that exercise-related damage and fatigue mediate inflammation, proliferation, and oxidative stress in most cases, it is hypothesized that CBD-related inhibitions in oxidative stress and neuroinflammation could have some therapeutic potential in sports research (Gamelin et al., 2020). This statement is based on evidence suggesting that CBD could induce changes in cortisol release, regulating inflammatory response to injury (Zuardi A. et al., 1993; Yeager et al., 2010). This mediation is due to the interaction between CBD CB_1, and CB_2 cannabinoids and adenosine receptors, leading to reduced cytokine levels and downregulating overreactive immune cells (Booz, 2011; Hill et al., 2012; Burstein, 2015). Also, CBD intake seems to mediate processes associated with gastrointestinal damage protection, due to inflammation, and promote healing of skeletal injuries (McCartney et al., 2020).

During exercise, mainly those actions with a high component of eccentric contraction are potentially and particularly damaging to the sarcolemma. This damage is fetterless in response to a disruption of the permeability of muscle cell membrane and basal lamina, allowing Ca^{2+} to reduce fiber electrochemical gradient. If the damage in the sarcolemma is relatively low, ATPase pumps attract Ca^{2+} and the damage is still reversible. Besides, if there is a Ca^{2+} overload, a degradation of the structural and contractile proteins could be provoked. The subsequent event is called the inflammatory cascade, recognized by the activation of macrophages and other phagocytic cells during the first 2–6 h after injury and prolonged for days (Armstrong et al., 1991; Burstein, 2015).

Additionally, CBD (300 mg) has been shown to induce changes in glucocorticoids as cortisol in humans (Zuardi A. W. et al., 1993), one of the primary homeostatic regulators of the inflammatory response to injury (Yeager et al., 2010). This is supported by a recent narrative review in sports, suggesting the potential anti-inflammatory effect in humans and the possible role in the performance of the athletes (McCartney et al., 2020). This affirmation is theoretically based on the suggested CBD capacity to interact with receptors involved in controlling inflammation as CB1 cannabinoid, CB2 cannabinoid, adenosine A2A, and also in reducing the levels of some cytokines, such as interleukin-1 (IL-1) and tumor necrosis factor α (TNFα), and downregulating overreactive immune cells reducing the impact of collateral inflammatory damage of tissues (Booz, 2011; Hill et al., 2012; Burstein, 2015). There is also evidence suggesting the CBD potential to promote the release of arachidonic acid, leading to greater healing capacity as a result of core regulation of growth signals mediated by proresolving substances, such as lipoxin A4 and 15d-PGJ2 (Burstein, 2015).

It is also known that the interplay between inflammation and oxidative stress underlies many human diseases due to tissue and organ damage. In this regard, in sports, it is hypothesized that CBD-related inhibitions in oxidative stress and neuroinflammation could have some therapeutic potential in sports research (Gamelin et al., 2020).

PAIN AND SORENESS

Cannabidiol has been commonly used for its analgesic properties (Kogan and Mechoulam, 2007) in a variety of pain disorders (Starowicz and Finn, 2017). CBD consumption could exhibit a beneficial effect over edema and hyperalgesia (Burstein, 2015; Hill et al., 2017), acting directly on the central nervous system and leading to sedative effects (Zuardi A. W. et al., 1993). The idea of considering CBD as an antinociceptive agent is based on the efficiency of treating the pain associated with proinflammatory cytokine release due to the activation of Vanilloid receptors, provoking antinociceptive effects and reducing the perception of pain (Booz, 2011). CBD could inhibit presynaptic neurotransmitters and neuropeptide release, modulate postsynaptic neuronal excitability, activate the descending inhibitory pain pathway, and reduce neuroinflammatory signaling (Starowicz and Finn, 2017).

Cannabidiol (300–400 mg) intake seems to have sedative effects on humans apparently acting directly on the central nervous system (Zuardi A. W. et al., 1993), supported by the idea that CBD exhibited a beneficial action over edema and hyperalgesia (Burstein, 2015; Hill et al., 2017). In this regard, drugs and substances such as Sativex, THC, and CBD are approved for the treatment of both central and peripheral neuropathic pain. This pain syndrome is associated with microglia activation and subsequent cascade of proinflammatory cytokines such as IL-6, IL-1β, and TNF (Booz, 2011). This evidence supports the idea of CBD use as an antinociceptive agent. Together with a neuroprotective quality, this effect was also found in a recent systematic review on the outcome of CBD intake in relation to its potential use as a sport-enhancing performance substance (McCartney et al., 2020). It still is unclear how CBD acts in relation to the pain cascade and pathways (Anthony et al., 2020). CBD has shown its potential to treat and manage pain in diseases and pain disorders, and based on this evidence CBD seems to have a potential effect on treating swelling and preventing soreness after strenuous exercise, but more evidence is required to make a clear statement.

SLEEP DISORDERS

Overreaching and overtraining are often presented in athletes due to high training loads accompanied by subsequent insufficient recovery between efforts (Fox et al., 2020). These abovementioned states are usually accompanied by sleep disorders and higher sleep disturbance, leading to poor sleep quality (Hainline et al., 2017). CBD consumption could stimulate the endocannabinoid system modulating sleep disorders and the sleep–wake cycle (Murillo-Rodríguez et al., 2020). Promising, but no specific, evidence suggests using cannabinoids like CBD to reduce sleep disorders in athletes or even in healthy or pathologic humans. Endocannabinoid system receptors as anandamide and type-1 are associated with sleep-promoting effects, but the physiological mechanism is not fully understood and is based mainly on preclinical studies (Suraev et al., 2020).

COGNITION AND MOOD

Evidence has shown that acute and single administration of CBD could have anxiolytic (Zuardi A. et al., 1993) and antidepressive effects through the activation of 5-HT1A receptors (Booz, 2011). Although the reported results are promising for sports recovery, evidence suggests no long-term impact on cognition or mood state due to prolonged use of CBD (Allendorfer et al., 2019; Martin et al., 2019). Also, the link between CBD consumption and the possible effect on exercise-related recovery is primarily clinical and preclinical studies, mostly in participants with background pathology (McCartney et al., 2020). In this sense, more in-depth analysis is needed in the population of athletes to reach a conclusive statement.

FUTURE RESEARCH AND LIMITATIONS

As interest in the use of CBD in athlete recovery continues to grow, more research is required to better understand the physiological mechanism. The potential benefits, efficacy, and purported safety profile when consuming CBD prior to, during, and after training or competition should be explored. Future research in the field of sports science and medicine must focus on understanding the role of CBD in physiological mechanisms such as inflammatory cascade, neuroprotection, analgesic and anxiolytic pathways, muscle enhancement, and neuromechanical function.

New randomized placebo-controlled studies should consider the different etiologies of fatigue and damage, individualities and disciplines, and special needs and characteristics. Other potential research areas are, but are not limited to, optimal dosing depending on physical and physiological load; effectiveness regarding administration timing; chronic and acute effects; cumulative responses with other recovery strategies; differences in tolerance and effectiveness by sex, professional level, and fitness level; and other individual conditions and situational factors. Besides, more information is needed around the understanding of CBD inflammatory signaling as an essential factor in the recovery process. The effectiveness of CBD vs. conventional medications should be assessed.

This narrative review must be analyzed in light of some limitations. Though the main evidence about the use of CBD in sports was reviewed, this systematic review lacks explicit criteria for article selection and inclusion. In this sense, a systematic review could strengthen the actual conclusions and better present the preclinical and clinical evidence supporting the use of CBD in sports recovery. In this sense, a systematic review could better present settings of tests, study designs, demographics of participants, and main conclusions of the recent evidence.

CONCLUSION

Evidence supporting the potential use of CBD as an ergogenic aid to improve the efficacy and efficiency of recovery processes during exercise and sport-related fatigue seems promising. Still, there is not enough information to be conclusive. CBD appears to have some properties that could boost exercise recovery as an anti-inflammatory, neuroprotective, analgesic, anxiolytic, and pain reliever. Still, due to the lack of studies in elite athletes, there is a need for a better understanding of the effects of CBD as a physiological, physical, and cognitive recovery agent.

More evidence and higher-quality studies are required in populations related to sports science and exercise medicine to be able to give recommendations regarding the dose and frequency of consumption as well as the specific prescribing of CBD according to the intensity and duration of the effort, as well as the role of essential characteristics such as body composition, general health, and other situational factors in its effect. Also, considering the lack of regulations in CBD production and indiscriminate consumption, athletes must be cautioned due to the high risk of testing positive in the doping tests.

Cannabidiol seems to have anti-inflammatory, neuroprotective, analgesic, anxiolytic, and pain-relieving properties which can be potential mediators of recovery in athletes during regular training and competition. To confirm these effects, more scientific evidence in specific sport-related populations is necessary. There is a need for confirmatory analyses using randomized, placebo-controlled trials testing acute, and chronic effects of different dosing prescriptions. This study must consider some fundamental particularities of sports as a great variety of biological and situational conditions that promote fatigue, the characteristics of each discipline during training and competition, as well as the individual peculiarities of athletes, their tolerance and response to CBD intake, and the combined effect of CBD administration with other physical and nutritional aids.

Since training and competition leads to a structural and functional imbalance due to strenuous effort, CBD intake could potentially promote restoration of physical performance. The CBD physiological mechanisms of action, mixed with other recovery protocols, could help to reduce the accumulated fatigue evident over a tournament of consecutive efforts. The above may depend on pointing to multiple mechanisms to provoke global functional recovery in sports. Much evidence is needed to support this conclusion, but the proposed evidence looks promising.

Considering the relatively common use of both cannabis and CBD alone among athletes, there is a clear need to improve scientific understanding of the effects of CBD use on the fatigue, damage-related recovery, and performance of athletes. Greater scientific progress is needed, mostly on the execution of experimental trials, allowing a greater understanding of both critical positive and negative outcomes for the final benefit of the athletes in exercise-related recovery and performance. Also, the evidence resulted could give new clinical guidance to prescribe CBD during the recovery process of an athlete and other possible applications. The potential therapeutic benefits of CBD administration have been downplayed for years but, the actual scenario could facilitate the boost of the knowledge around this natural compound and its effects. Besides, from an administrative point of view, clearer and overarching policy for the use of cannabis in sports need to be considered and adopted.

Finally, athletes have to create an optimal internal environment to increase the function of endocannabinoids. In this sense, besides regular exercise, athletes must control weight, manage stress and competition-related anxiety, and minimize environmental exposure to contaminants and other toxic substances. These cannabimimetic practices would create the ideal environment for improving the endocannabinoid action in recovery.

AUTHOR CONTRIBUTIONS

DR-V carried out the original idea conceptualization, literature search and systematization, writing the original draft, critically revising the manuscript, funding, and approving the final manuscript.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Physiology

ORIGINAL RESEARCH
published: 19 August 2021
doi: 10.3389/fphys.2021.690353

Weekly Variations of Short-Duration Maximal Jumping Performance in Soccer Players: Exploring Relationships With Accumulated Training Load and Match Demands

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OPEN ACCESS

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *02 April 2021*
Accepted: *20 July 2021*
Published: *19 August 2021*

Citation:
Silva R, Clemente FM, González-Fernández FT, Bernardo A and Ardigò LP (2021) Weekly Variations of Short-Duration Maximal Jumping Performance in Soccer Players: Exploring Relationships With Accumulated Training Load and Match Demands. Front. Physiol. 12:690353. doi: 10.3389/fphys.2021.690353

Purpose: The aim of this study was 2-fold: (1) to analyze variations of short-duration maximal jumping performance in players exposed to a match and those who were not and (2) to analyze the relationships between changes in the short-duration maximal jumping performance and different accumulated training load and match demands measures.

Methods: Twenty-four professional soccer players (age: 20.3 ± 1.7 years) were monitored daily for their training load and match demands over 6 weeks. In addition, they performed a weekly short-duration maximal jumping performance test (72 h after the last match).

Results: Negative moderate correlations were found between percentage of change of countermovement jump (CMJ) height and Acummulated training load (ATL) of total distance (TD), high metabolic load (HML), accelerations (ACC), and decelerations (DEC) ($r = -0.38$, $p = 0.004$; $r = -0.33$, $p = 0.013$; $r = -0.39$, $p = 0.003$; and $r = -0.30$, $p = 0.026$). No correlations were found for match load (ML). TD, HML, ACC, and DCC ($r = 0.27$, $r = 0.25$, $r = 0.31$, and $r = 0.22$, respectively) were used to predict the percentage of change of CMJ height.

Conclusion: Match participation has negative effects on CMJ performance. The ATL of HML, ACC, DCC, and TD have a significant influence on both CMJ measures changes. Also, the ATL values of those metrics are the best predictors of the percentage changes of CMJ performance.

Keywords: football, readiness, muscle fatigue, athletic performance, sports training

INTRODUCTION

Research done over the past few years shows that modern soccer players experience substantial increases in high-intensity activities during training and competitions (Barnes et al., 2014). These increased demands are accompanied by a training schedule that limits recovery after a training week that ends with a highly demanding match. Increased weekly training loads, combined with demanding soccer matches, result in accumulated fatigue, which may negatively impact the performance of players during and after competitions and during subsequent training cycles (Haddad et al., 2013; Brownstein et al., 2017).

During a soccer match, athletes are expected to manifest temporary neuromuscular fatigue and performance reduction during different stages of the match, especially after short periods of high-intensity actions during both halves and near the end of the match (Bangsbo et al., 2007). Thus, after a single soccer match, athletes experience decreased physical performance for up to 72 h, as a result of fatigue (Silva et al., 2018). Indeed, a recent systematic review on this topic revealed that jump performance is impaired 72 h post-match while sprinting performance seems to recover at this time (Silva et al., 2018). Neuromuscular fatigue results in decreased force-production capacity concurrent with impairments in the muscle-stretch-shortening cycle (SSC), which are relevant issues for injury prevention and soccer performance maintenance perspectives (Debenham et al., 2015). Furthermore, regarding the recovery process after training and competition, the high between-subjects and between-weeks variations that might be present in a soccer team must be considered (Nédélec et al., 2012). In turn, over a repeated-sprint-ability exercise viz. a proxy for soccer running, a countermovement jump (CMJ)-based recovery was effective in increasing training load [e.g., the subjective rate of perceived exertion (RPE); Foster et al., 2001] without harming running mechanics (i.e., SSC).

Therefore, analyzing vertical jump performance variations after a soccer match is of paramount importance, especially if there is no other option available to assess neuromuscular fatigue after strenuous activity. In that sense, a recent study analyzed whether CMJ variables could track acute fatigue effects 24 and 48 h after a simulated soccer match. The results revealed that none of the CMJ metrics manifested any changes (Lombard et al., 2020). Indeed, it was previously shown that CMJ height did not vary during an in-season training week (without considering the match) and no correlations were found between weekly training loads and CMJ changes (Malone et al., 2015). On the contrary, another study documented that CMJ performance was negatively affected by training load and that there was a cumulative effect of weekly training loads on neuromuscular fatigue (Tavares et al., 2018). Interestingly, a recent systematic review analyzed the correlations between match external-load activities and acute (up to 24 h) and residual (up to 72 h) fatigue markers. The findings indicate that very high-intensity running activities (>5.5 ms^{-1}) are strongly correlated with decreased neuromuscular performance based on the CMJ test, but only when they were assessed during the first 24 h after a match (Hader et al., 2019).

Also of great importance is understanding and monitoring neuromuscular fatigue of teams after a training week ending with a soccer match. Different assessment approaches and their related limitations have been documented (Wehbe et al., 2015; Carling et al., 2018; Troester and Duffield, 2019). By these means, coaches are equipped with enhanced knowledge of how their athletes respond to training and competitions, thereby allowing them to adjust training accordingly to prevent injuries and overtraining (Foster, 1998; McLean et al., 2010). From the different methodological assessments available for measuring the readiness of an athlete to train (i.e., detecting neuromuscular fatigue), the CMJ is a practical tool for detecting weekly neuromuscular performance changes (Claudino et al., 2017). Indeed, CMJ data analysis, when used to objectively quantify neuromuscular fatigue, revealed a lower coefficient of variation (<5%) for jump height than other relevant variables, thus confirming its reliability (Gathercole et al., 2015).

A short-duration maximal jumping testing protocol consisting of four CMJ repetitions interspersed by 3–5 s of recovery revealed that peak jump velocity might be more sensitive to fatigue detection when practitioners do not have any other means of assessing readiness to train than jump testing (Mathieu et al., 2017). Indeed, practitioners can use this tool to monitor the effects of fatigue after team sports training and competitions as well as to assess resistance training neuromuscular readiness (Watkins et al., 2017).

Although many studies have investigated the effects of match loads on acute and residual neuromuscular fatigue (Silva et al., 2018), few studies have explored the relationships between match and accumulated loads with changes in neuromuscular performance (Rowell et al., 2018; Clemente et al., 2019). In addition, to the best of our knowledge, no study has investigated the associations between accumulated external training loads and changes in neuromuscular performance assessed *via* CMJ measures. For those reasons, and considering the importance of insights into the effects of weekly training loads and match demands on residual neuromuscular fatigue, the aims of this study were (1) to analyze variations in short-duration maximal jumping performance in players exposed to matches and those who were not and (2) to analyze the relationships between changes in the short-duration maximal jumping performance and different measures of accumulated training load and match demands.

METHODS

Experimental Approach to the Problem

This study followed an observational analytic cohort design. The included players were analyzed over six non-consecutive weeks between October 13, 2020, and December 5, 2020 (i.e., from the beginning of the in-season period to the midseason) (**Table 1**).

Eligible players were always tested 72 h after the most recent match using a short-duration maximal jumping performance test. Between one assessment and the next (i.e., the next week), the players were monitored daily by using internal and external load measures (**Figure 1**). Accumulated training load (ATL, sum of weekly training sessions loads) and match load (ML, average

TABLE 1 | Characterization of the analyzed weeks in this study.

Variable	Week 10–11	Week 11–12	Week 12–13	Week15–16	Week 16–17
Month	October	October	November	November	December
Training sessions (*n*)	5 + M + 5	5 + M + 4	4 + M + 5	4 + M + 5	5 + M + 4
PPM (*n*)	16	14	No match	13	12
PNPM (*n*)	2	4	No match	2	2

M, match; PPM, players participating in the match; PNPM, players not participating in the match.

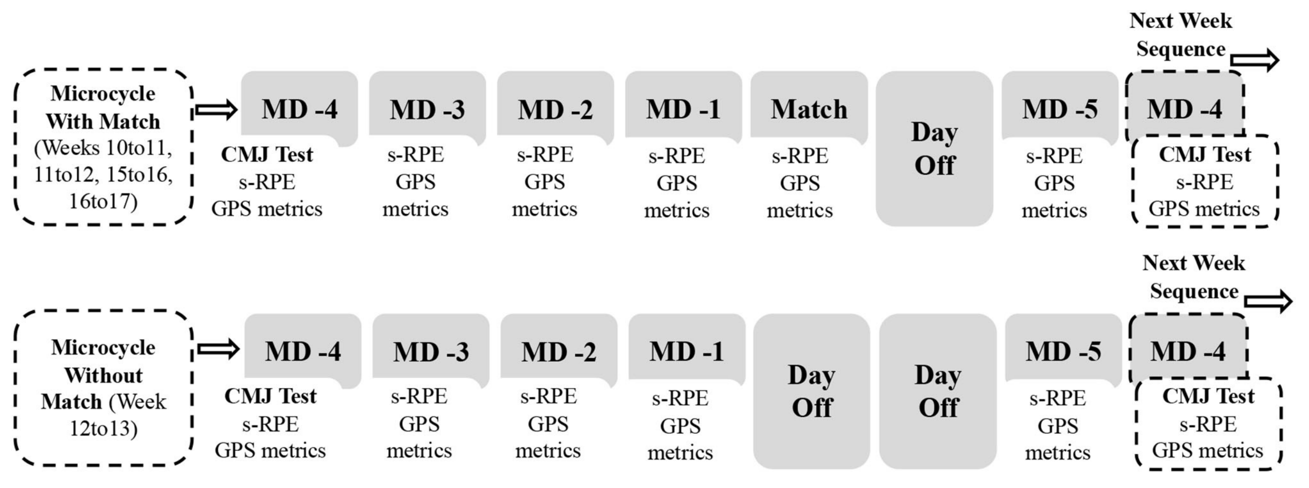

FIGURE 1 | Representation of a weekly data collection sequence.

of in-between match loads) demands were registered. For the players not participating in the match, only the accumulated training load was considered.

Participants

Twenty-four professional soccer players (age: 20.3 ± 1.7 years; body mass: 70.6 ± 7.0 kg; height: 179.1 ± 7.1 cm; years of experience: 11.5 ± 2.7; baseline CMJ height: 39.3 ± 5.2) voluntarily participated in this study. The players belonged to the same club, which competed in the third league of Portugal.

During each week of the observational period, the team had five training sessions (with an average session duration of 78.8 ± 15.6 min) and one official match. Only regular weeks (i.e., those with only one official match) were considered for analysis. For assessing readiness-to-train status of the teams, a short-duration maximal jumping performance test was conducted before the start of each match-day-4 (MD-4) training session. The training microcycle comprised of MD-5 (recovery), MD-4 (tension), MD-3 (duration), MD-2 (speed), and MD-1 (reactive speed).

For each observed week, the inclusion criteria for a player to be included in the data treatment were as follows: (1) the player participated in the pre- or post-match assessment (i.e., maximal jumping performance test), (2) the player was neither injured nor ill, nor did they miss any training sessions between the pre- and post-match assessments; (3) the player was not injured or ill the week before the assessment.

Before the beginning of the study, the players were informed about the study design and protocol as well as the risks and benefits of participating. After voluntarily deciding to participate, they signed an informed consent that explicitly stated that they were free to end the process at any time with no consequences. The study protocol was approved by a scientific council of the local university and followed the ethical standards of the Declaration of Helsinki for the study of humans.

Short-Duration Maximal Jumping Performance Test

For the assessment of the short-duration maximal jump performance test, each player was requested to complete four CMJ repetitions interspersed by 3–5 s of recovery between jumps (Mathieu et al., 2017). Players were instructed to maintain both hands on their hips during the four trials to keep their back straight without swinging their legs forward during the flight phase and to try to land in the same place they took off from, landing with the tips of their toes first. Participants were allowed to perform the CMJ at the depth that was most suitable for them.

All jumps were assessed using an Optojump photoelectric cells system (Microgate, Bolzano, Italy) connected to a portable computer with its respective software (Optojump software, version 1.10.19). Jump height was estimated as 9.8 × flight time^2/8 and used for further analysis (Glatthorn et al., 2011). All measurements were conducted during the morning and before practice sessions. Although better jump performance was previously documented during the late afternoon, it seems that similar performance might be observed during the morning if certain criteria are met (Mirizio et al., 2020).

A standardized warm-up consisting of ankle mobility and knee range of motion exercises followed by three to five submaximal CMJs was conducted. After the warm-up, athletes rested for ∼3 min before performing the four CMJ trials.

Internal Load

For measuring the internal loads, RPE data were collected ∼10–30 min after each training session, similarly to previous research (Foster et al., 2001). The CR-10 scale was used to quantify session effort of each player (Borg, 1998). Based on the CR-10 scale, 1 means "very light activity" and 10 means "maximal exertion." Each player rated the effort individually, without being influenced by the other players, by using a smartphone questionnaire that asked, "How hard was your training?" All the players were previously familiarized with this kind of perceptual effort rating. The internal training loads were then obtained by multiplying the training session of each player, RPE (s-RPE), by the absolute time of each session (in minutes) (Foster, 1998).

External Load

Each player used the same 18 Hz GPS unit (STATSports, Apex, Northern Ireland) during the period of the study. The GPS units have an integrated 100 Hz gyroscope, 100 Hz tri-axial accelerometer, and 10 Hz magnetometer. The GPS model used in this study was previously tested for its validity and reliability, revealing good levels of accuracy and variability at different speed thresholds and excellent interunit reliability for peak velocity (Beato et al., 2018; Beato and de Keijzer, 2019). The GPS units were placed in a specific vest in which the unit was fixed between the scapulae. The data collected during training sessions and matches were imported and processed in the STATSport Sonra software (version 3.0).

The following measures were collected daily during each training session and match: (1) total distance (TD: consisting in the total distance covered by players); (2) distance covered at high-speed running (HSR: distances covered at a speed of 19.8 km h^{-1} or above); (3) high metabolic load distances (HML: distances covered at a speed of >19.8 km h^{-1} while accelerating/decelerating at ≥2 m s^{-2}); (4) high-intensity accelerations and decelerations (ACC and DEC: number of accelerations and decelerations at ≥3 m s^{-2}); (5) sprint distances at 80% of the maximal speed ($_{80\%}$SD: distances covered at a speed corresponding to 80% of the actual maximal speed of each player).

Statistical Procedures

For the treatment of the data, we use adequate statistical methods to calculate percentages and central and dispersion parameters (arithmetic mean and SD). The normal distribution of data was tested using the Kolmogorov–Smirnov test. CMJ pre-match and CMJ post-match measurements were assessed using a two-way, mixed-design ANOVA for group condition (played or not played match in-between) and time condition (pre- or post-match). Posteriorly, planned comparisons were performed to evaluate differences between times. A repeated-measure ANOVA was used to analyze the CMJ height (pre- and post-match) and times (week 10–11, 11–12, 12–13, 15–16, and 16–17). Effect size is indicated with Cohen's d for t-tests [0.2 (small); 0.5 (medium) and >0.8 (large)] and partial eta squared for Fs. A Pearson's correlation coefficient r was used to examine the relationship between the percentage of change of CMJ [CMJ (pre-match – post-match)] and the remaining variables (TD, HSR, HML, Sprint, ACC, DCC, CR-10, and sRPE). To interpret the magnitude of these correlations, we adopted the following criteria (Granier et al., 1995): $r \leq 0.1$, trivial; $0.1 < r \leq 0.3$, small; $0.3 < r \leq 0.5$, moderate; $0.5 < r \leq 0.7$, large; $0.7 < r \leq 0.9$, very large; and $r > 0.9$, almost perfect. Regression analysis was used to model the prediction of both percentages of change from remaining variables with positive correlation. Data were analyzed by using the software Statistica (version 10.0; Statsoft, Inc., Tulsa, OK, USA). For all analyses, significance was accepted at $p < 0.05$.

TABLE 2 | Descriptive statistics (mean ± SD) for the pre- and post-match countermovement jump (CMJ) (mean value) to those played and not played matches in between.

	Pre-match CMJ (cm)	Post-match CMJ (cm)	Post-match – Pre-match CMJ (cm) % |*p*| *d*
Matches in between	40.14 ± 3.54	39.06 ± 3.44	−3.02% |0.005| 0.43
No matches in between	41.19 ± 4.67	42.23 ± 4.86	2.32% |0.02| −0.21

RESULTS

Descriptive statistics were calculated for each variable (refer to **Tables 2**, **3**, for more information).

A two-way mixed design ANOVA with mean data of CMJ (**Table 2**) revealed a significant main effect of group condition, $F_{(1.74)} = 5.06$, $p = 0.02$, $\eta^2 = 0.06$. The effect of time condition, $F < 1$, was not significant. The interaction between group and time condition revealed a significant effect, $F_{(1.74)} = 10.14$, $p = 0.002$, $\eta^2 = 0.12$.

A repeated-measures ANOVA with mean data of CMJ and time did not reveal any significant effect, $F_{(4.65)} = 1.40$, $p = 0.24$, $\eta^2 = 0.07$, and $F_{(1.65)} = 3.78$, $p = 0.056$, $\eta^2 = 0.05$, respectively. The interaction between group and time condition revealed a significant effect, $F_{(4.65)} = 4.07$, $p = 0.005$, $\eta^2 = 0.20$. The pairwise comparisons showed significant differences between CMJ-pre and post in Week 10–11, 12–13, and 16–17, $t_{(15)} = 2.50$, $p < 0.02$, $d = 0.53$, $t_{(14)} = 2.52$, $p < 0.02$, $d = 0.03$, and $t_{(11)} = 2.21$, $p < 0.04$, $d = -0.28$, respectively. A pairwise comparison between CMJ-pre and post in Week 11–12, Week 15–16 was not significant, $t_{(13)} = 0.22$, $p < 0.82$, $d = 0.07$,

TABLE 3 | Description (mean ± SD) of accumulated training load and match load (ML) demands.

	TD (m)	HSR (m)	HML (m)	ACC (*n*)	DCC (*n*)	Sprint (m)	CR-10 (A.U.)	sRPE (A.U.)
ML	6,697.89 ± 2,550.21	457.77 ± 219.08	1,251.57 ± 500.62	64.33 ± 25.78	65.31 ± 26.55	40.55 ± 133.80	6.97 ± 1.34	500.68 ± 201.56
ATL	43,897.93 ± 10,747.09	2,453.60 ± 1,066.37	7,343.06 ± 1,870.24	550.15 ± 131.11	474.75 ± 131.11	75.56 ± 52.99	4.40 ± 0.69	3,152.51 ± 836.12

ATL, Accumulated training load; ML, match load; TD, total distance; HSR, high-speed running; HML, high metabolic distance; ACC and DCC, high-intensity accelerations and decelerations (number of accelerations and decelerations at ≥ 3 m/s^{-2}); CR-10, rate of perceived exertion at CR-10 Borg scale; sRPE, session-RPE (score at CR-10 multiplied by the duration of the session in minutes).

TABLE 4 | Correlation between percentage of change of CMJ and accumulated training load and ML demands.

			TD (m)	HSR (m)	HML (m)	ACC (*n*)	DCC (*n*)	Sprint (m)	CR-10 (A.U.)	sRPE (A.U.)
ATL	% of change CMJ height	*r*	−0.3889	−0.1230	−0.3353	−0.3973	−0.3030	−0.1145	0.1169	−0.2314
		p	0.004*	0.37	0.013*	0.003*	0.026*	−0.41	0.40	0.092
ML	% of change CMJ height	*r*	0.0313	0.0287	0.0329	0.0663	0.0698	0.0653	0.0115	0.1136
		p	0.824	0.838	0.815	0.637	0.620	0.642	0.935	0.418

*ATL, Accumulated training load; ML, match load; TD, total distance; HSR, high-speed running; HML, high metabolic distance; ACC and DCC, high intensity accelerations and decelerations (number of accelerations and decelerations at ≥ 3 m/s^{-2}); CR-10, rate of perceived exertion at CR-10 Borg scale; sRPE, session-RPE (score at CR-10 multiplied by duration of the session in minutes); CMJ, countermovement jump. * refers to statistical significance at p < 0.05.*

TABLE 5 | Values of regression analysis explaining the percentage of b* change of CMJ b* on the remaining R variables.

			b*	SE of b*	*R*	R^2	Adjusted R^2	*F*	*p*
ATL	TD	% of ChangeCMJ Height	−0.27	0.13	0.27	0.07	0.05	4.14	0.04*
	HML	% of ChangeCMJ Height	−0.25	0.13	0.25	0.06	0.04	3.54	0.06
	ACC	% of ChangeCMJ Height	−0.31	0.13	0.31	0.09	0.07	5.58	0.02*
	DCC	% of ChangeCMJ Height	−0.22	0.13	0.22	0.05	0.03	2.89	0.09

*ATL, Accumulated training load; TD, total distance; HML, high metabolic distance; ACC and DCC, high-intensity accelerations and decelerations (number of accelerations and decelerations at ≥3 m s^{-2}); CMJ, countermovement jump. * refers to statistical significance at p < 0.05.*

$t_{(12)} = 0.39$, $p < 0.69$, $d = 58$, respectively (refer to **Figure 2** for more information).

At this point, we wondered about the possible associations between percentage of change of CMJ (pre-match – post-match) and the remaining variables (TD, HSR, HML, Sprint, ACC, DCC, CR-10, and sRPE) (refer to **Table 3**, for more information). Thus, the correlation analysis between the percentage of change of CMJ height and accumulated training load showed no significant correlations between percentage of change of CMJ height and HSR, Sprint, CR-10, and sRPE. However, negative moderate correlations were found between percentage of change of CMJ height and TD, HML, ACC and DCC ($r = -0.38$, $p = 0.004$; $r = -0.33$, $p = 0.013$; $r = -0.39$, $p = 0.003$, and $r = -0.30$, $p = 0.026$). A correlation analysis between the percentage of change of CMJ [CMJ (pre-match – post-match) and match load demands showed no significant correlations between any variable (refer to **Table 4**, for more information).

A multilinear regression analysis was performed to verify which variable of accumulated training load (agreement with the correlation analysis) could be used to better explain the percentage of change of CMJ Height. TD, HML, ACC and DCC were predictors of the percentage of change of CMJ Height ($r = 0.27$, $r = 0.25$, $r = 0.31$, and $r = 0.22$, respectively) (refer to **Table 5**, for more information).

DISCUSSION

The purposes of this study were (1) to analyze variations in CMJ measures considering match participation and (2) to analyze the relationships between CMJ measures variations and ATL and ML values. The main findings revealed that match participation was the factor with the greatest influence on changes in both CMJ measures. The week without a match was the only one with significant increases in jump performance. The ATL values of TD, HML, ACC, and DCC had a greater influence (moderate correlations) than ML on changes in CMJ height. Also, TD, HML, ACC, and DCC predicted variations in both CMJ measures.

Regarding the first objective, the time condition (pre-post assessments) was not the main factor influencing differences in CMJ measures. Similar to these results, another study revealed that the time condition (pre- or post-assessments) had no significant effect on CMJ height changes (Stone et al., 2016). Indeed, a recent study that aimed to analyze

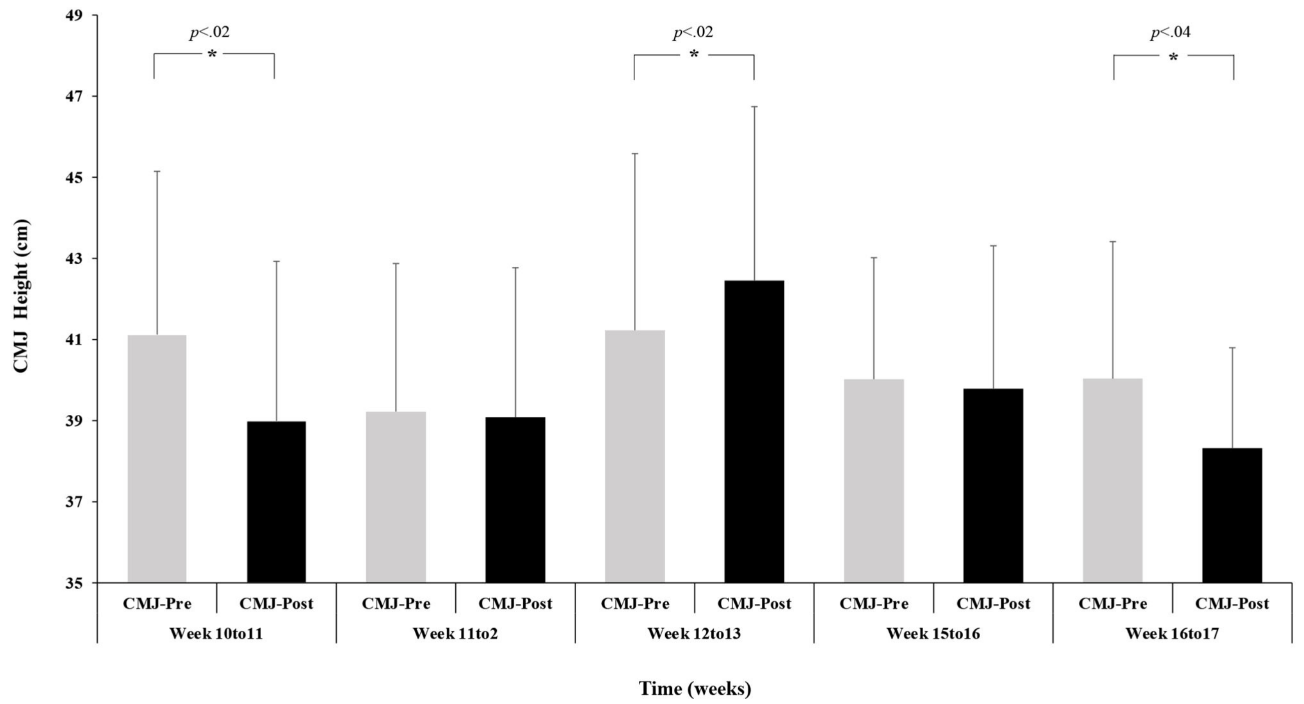

FIGURE 2 | Pre- and post-match countermovement jump (CMJ) height (mean value ± SE) as a function of time (weeks).

variations in CMJ measures, including jump height, after a simulated soccer match revealed that none of the CMJ-related measures changed significantly between assessments (Lombard et al., 2020).

Notwithstanding the above-mentioned similarities, the above-mentioned studies were conducted on a small non-professional sample by using a simulated soccer match. Indeed, simulated soccer match protocols revealed similar physiological and technical demands as official matches (Russell et al., 2011). However, this type of protocol is usually tested over very short periods (pre- or post-assessments within a week). Other contextual factors, such as the quality of opposition and coach encouragement, might also influence the responses of the players during a training week and the official matches in-between (Guerrero-Calderón et al., 2021). Therefore, these different methodological approaches between studies make comparisons with these findings difficult.

Furthermore, in the present study, the only analyzed week sequence that showed increases in both CMJ measures was the weekly sequence without a match in between, namely, the period from Week 12 to Week 13. This appears to reinforce previous findings, revealing the fatigue effects that a single match has on jump performance (Stone et al., 2016; Lombard et al., 2020). This is especially true for CMJ performance due to its natural characteristics (SSC abilities), suggesting a need for longer (>72 h) recovery periods (Silva et al., 2018). This highlights the need for practitioners to analyze CMJ height for up to 72 h after a match to ensure that athletes who participated in the match were given enough time to recover and are ready to train. By doing this, coaches can be more confident in their decisions to select specific players for the next match.

Interestingly, these results revealed that the ATL of all the analyzed accelerometry-based GPS metrics (HML, ACC, and DCC) had moderate relationships with the percentage of change of CMJ height. At the same time, no associations were found for ML. Another study that assessed neuromuscular performance before and after a youth soccer match revealed that the isometric strength of knee extensors and flexors and the rate of force development decreased by up to ∼10%, whereas CMJ performance remained unchanged (Thorlund et al., 2009). This is somewhat similar to these results, as the authors of the aforementioned study considered only pre- or post-match (ML) CMJ changes without considering the preceding weekly training loads (ATL) as in the present study (Thorlund et al., 2009).

However, another study revealed that CMJ height was impacted by match load but only between 0.5 and 18 h post-match (Rowell et al., 2017). The authors of the above-mentioned study suggested that CMJ height is more sensitive to track immediate neuromuscular changes after a match, while the FC:CT ratio seems better suited to track neuromuscular changes at longer time-frames (Rowell et al., 2017). This fact might explain why there were no relationships between the percentage of change of CMJ measures and match load demands in the present study.

Furthermore, these findings showed no significant relationships between the percentage of change of CMJ measures and ATL and ML subjective internal load measures. A previous study conducted on 19 professional soccer players revealed that sRPE (relative to leg muscle effort perceptions) and its related accumulated training load had negative correlations (r range $= -0.52$ to -0.61) with changes in CMJ height after a 9 week training period with matches in between (Arcos et al., 2015). However, it must be highlighted that the negative correlations found in that study were related to changes in single-leg (dominant- and non-dominant) CMJ protocols (Arcos et al., 2015). Indeed, the above-mentioned study revealed no significant associations between sRPE measures and bilateral CMJ changes (r range $= -0.17$ to -0.20), using the both-hands-on-hips protocol (as in the present study), which is in concordance with these findings. To the best of our knowledge, no other study has tested these relationships. Thus, future studies should confirm this lack of relationships.

It was previously documented that soccer match demands are associated with acute and residual fatigue effects on the performance of soccer players (Nedelec et al., 2011; Silva et al., 2013). As revealed in the present study, it seems that the ATL of accelerometry-based metrics and TD might have a greater impact, at least on the neuromuscular fatigue of players. Indeed, the multilinear regression confirmed that the weekly training loads of TD, HML, ACC, and DCC were the best predictors of the percentage changes in CMJ performance.

Interestingly, a study conducted on 27 professional soccer players revealed that weekly TD and the number of high accelerations/decelerations are three to four times greater than the demands of a soccer match (Clemente et al., 2019). Based on such findings, it can be argued that the ATL of these metrics has a stronger fatigue effect than only ML on neuromuscular performance (as demonstrated in the present study). That is, the players with higher ATL of TD, HML, ACC, and DCC are less likely than other players to experience improved jump performance, 72 h post-match. However, the short duration maximal CMJ jump test was conducted 1 day after the first weekly training session (MD-4; recovery day) in the present study, which might have influenced such findings.

Although, coaches should exercise some caution when planning weekly high accelerations and decelerations ($\geq$3 m s^{-2}) ATL, as they have been associated with high neuromuscular fatigue levels and increased injury risk if not monitored properly (Harper et al., 2019). Indeed, a study conducted on 15 elite U-19 soccer players revealed correlations between decelerations ($>$2 m s^{-2}) and CMJ concentric and eccentric forces (de Hoyo et al., 2016). The above-mentioned study also suggested that accelerometry-based metrics can predict neuromuscular performance changes up to 48 h after a match (de Hoyo et al., 2016). For those reasons, the negative effects that accelerometry-based metrics have on neuromuscular performance, especially deceleration measures, must be addressed (Gastin et al., 2019). Also, coaches and practitioners must carefully manage these ATL-related metrics and ensure that the appropriate strategies are followed to increase the resilience of players to deceleration and acceleration loads (Harper and Kiely, 2018).

This study had some limitations. One of the main limitations was the small sample size. However, this is a common issue in studies conducted in professional team settings. Furthermore, the use of a short-duration maximal jump test protocol during MD-4 (recovery) training sessions (72 h after the previous match) could have influenced the results. Future studies should analyze variations in CMJ measures before the start of a new training microcycle (e.g., on MD-5). Another limitation is related to the CMJ measures used, as they may not be the most sensitive to the assessed changes. However, a force platform was not available to implement other measures. Future studies should use other neuromuscular measures to reinforce the present findings.

CONCLUSION

Match participation was the main factor influencing CMJ performance. The ATL values of HML, ACC, DCC, and TD had moderate correlations with both percentage changes of CMJ measures. Those metrics were also the best predictors of the percentage changes of CMJ measures according to linear regression analysis. Coaches and practitioners must monitor and manage weekly accelerometry-based metrics considering the next match and implement strategies to increase the resilience of players to accelerometry demands.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Escola Superior de Desporto e Lazer, Instituto Politécnico de Viana do Castelo. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RS and FC lead the project, established the protocol, and written, and revised the original manuscript. FG-F and LPA have also written and revised the original manuscript. AB helped in data collection and revised the final document. All authors contributed to the article and approved the submitted version.

FUNDING

FC: This work was funded by Fundação para a Ciência e Tecnologia/ Ministério da Ciência, Tecnologia e Ensino Superior through national funds, and, when applicable, cofunded EU funds under the project UIDB/50008/2020. RS: This study made part of one curricular unit of Master in Sports Training at Escola Superior de Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Portugal.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers in Physiology

ORIGINAL RESEARCH
published: 17 September 2021
doi: 10.3389/fphys.2021.719580

Effects of Three Preseason Training Programs on Speed, Change-of-Direction, and Endurance in Recreationally Trained Soccer Players

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Background: Modern coaches experience a drastic reduction of the available training time with an increasingly large number of competitions during the competitive season. Thus, they must choose wisely the most efficient methods to improve the physical fitness of their players during the preseason. Among all the methods, this study compared the effects of plyometric training (PT), sprint interval training (SIT), and small-sided games (SSGs) on the performance of recreationally trained soccer players.

Methods: Seventy-three participants were randomly assigned in one of the three experimental groups (i.e., PT [$n = 23$], SIT [$n = 26$] or SSGs [$n = 24$]) and completed two sessions per week for a total of 3 weeks. Meanwhile, the whole group maintained their habitual soccer-specific training program who do not interfere in the preparation of the season. Repeated sprint ability (RSA), maximal aerobic speed (MAS), and a 30-m sprint were assessed at baseline (PRE) and post-training (POST).

Results: Performance in SSGs decreased for the average speed from 0 to 10 m (V_{0-10m}; −0.84 km h^{-1}, −4 ± 5%, $p < 0.001$), the maximal distance (D_{max}) covered in the 30-s RSA test (−3.65 m, −3 ± 6%, $p < 0.01$) and MAS (−0.52 km h^{-1}, −3 ± 6%, $p < 0.01$). PT increased the mean distance (D_{mean}) covered in the 30-s RSA test (+5.98 m, 5 ± 4%, $p < 0.001$) and MAS (+0.58 km h^{-1}, 7 ± 5%, $p < 0.01$) while an improvement of all parameters but the maximal sprint speed reached during the 30-m trip (V_{max}) was found in the SIT group (V_{0-10m}: +1.462 km h^{-1}, 8 ± 5%, $p < 0.001$; D_{max}: +7.89 m, 6 ± 5%, $p < 0.001$; D_{mean}: +8.69 m, 7 ± 5%, $p < 0.001$ and MAS: +1.74 km h^{-1}, 12 ± 8%, $p < 0.001$). All SSG POST values were significantly lower than PT and SIT ($p < 0.01$). D_{mean} and MAS in POST were also significantly higher in SIT than in the PT group ($p < 0.001$).

Conclusion: This study suggests that both PT and SIT could be a better alternative to SSGs to boost performances during preseason. Moreover, SIT seems to produce higher improvements in physical performances than PT.

Keywords: repeated sprints, change-of-direction, power, strength, endurance, soccer

Edited by:
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Reviewed by:
David Cristóbal Andrade, University of Antofagasta, Chile
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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *02 June 2021*
Accepted: *20 August 2021*
Published: *17 September 2021*

Citation:
Koral J, Lloria Varella J, Lazaro Romero F and Foschia C (2021) Effects of Three Preseason Training Programs on Speed, Change-of-Direction, and Endurance in Recreationally Trained Soccer Players. Front. Physiol. 12:719580. doi: 10.3389/fphys.2021.719580

INTRODUCTION

Soccer is an invasive team field game with an intermittent activity profile (Drust et al., 2000), which is characterized by around 1,200 acyclical, very variable, and unpredictable actions (Iaia et al., 2009). Those bouts involve various types of linear sprints interspersed with rapid changes-of-direction (CoD), decelerations, sudden starts, stops, jumps, kicks, and tackles (Bloomfield et al., 2007; Iaia et al., 2009; Pavillon et al., 2021). More specifically, it is well-established that during a professional soccer match, an average of 80% of physical activities is considered as low-to-moderate intensities such as standing, walking, or jogging, and the remaining 20% of physical activities are classified as high-intensity activities (running 12–20 km h^{--1}) or sprints (Mohr et al., 2003; Bloomfield et al., 2007; Pavillon et al., 2021). Despite those last intense actions that have been reported to occur only each 60 s for high intensities (Strudwick et al., 2002) or every 4–5 min for the sprints (Drust et al., 2000; Strudwick et al., 2002; Rampinini et al., 2007a), they are crucial and nearly always precede match-winning actions such as goal situation (Faude et al., 2012).

Consequently, both coaches and researchers have focused on determining the optimal training methods (i.e., strength training and repeated sprint training) for the development of CoD and repeated maximal linear sprint performance, which constitute the key physical qualities in soccer (Cometti et al., 2001; Markovic et al., 2007; Faude et al., 2012; Trecroci et al., 2016, 2020; Pavillon et al., 2021). To do so, three main approaches are usually considered. The first two are inspired by track and field training methods, one focused on strength training and another on traditional running-based conditional exercises, whereas the last one is more ecological and tries to mimic as much as possible the game conditions.

The strength training approach is based on several studies that reported strong correlations between lower-body strength and short-sprint performance (Seitz et al., 2014). For instance, maximal strength is reported to be one of the most important factors in maximizing power output (Cronin and Hansen, 2005; Weyand et al., 2006, 2010; Thapa et al., 2021). Hence, there is no doubt about the beneficial effects of strength training to increase short-sprint performance (Styles et al., 2016) and/or sprint ability (Markovic et al., 2007). Up to now, practitioners and researchers have mostly focused on heavy resistance training and plyometric training (PT) in soccer (De Hoyo et al., 2016; Bauer et al., 2019; Ramirez-Campillo et al., 2020). Most of them tend to agree that PT, due to a rapid eccentric to concentric muscle contraction, represents a method of choice when aiming to enhance a wide range of athletic performance particularly those involving the stretch-shortening cycle (SSC) such as jumping, sprinting, and agility (Fatouros et al., 2000; Markovic et al., 2007; Slimani et al., 2016; Negra et al., 2020). Thapa et al. (2021) even considered PT as a bridge between strength and speed. Nevertheless, as the distance traveled during a game is comprised between 9,995 and 11,233 m (Rampinini et al., 2007a), soccer relies primarily on aerobic metabolism for energy (Strøyer et al., 2004). In addition, when measuring the effects of PT on endurance in soccer, the results are more contrasted.

The second approach is a direct consequence of the aforementioned necessity of developing endurance. Coaches usually dedicate a non-negligible amount of time during the preseason to improve this capacity because they are aware that the aerobic pathway and more specifically VO_2max are of crucial importance in soccer (Mallo and Navarro, 2008). For instance, Helgerud et al. (2001) reported that the higher the VO_2max and running economy, the better the performances during the game. Moreover, the optimization of VO_2max has been reported (i) to allow better repeat sprints (Glaister, 2005), (ii) to better recover between each sprint (Aziz et al., 2007; Brown et al., 2007), and therefore (iii) to maintain higher sprint velocity during the game (Bishop and Edge, 2006). In addition, traditional running-based training programs have been broadly studied, especially when based on very high intensities. Those methods seem to be focused on enhancing maximal performance while reducing the total workout time. Among these techniques, sprint interval training (SIT) seems particularly interesting, because (i) it is nearly costless as no special equipment is needed; (ii) it generates improvements not only in all muscle energy pathways (i.e., aerobic and anaerobic; Parra et al., 2000; Rodas et al., 2000; Ross and Leveritt, 2001; Burgomaster et al., 2007; Weston et al., 2014; Milanović et al., 2015) but also on endurance, strength, power, and speed performance (Taylor et al., 2015; Koral et al., 2018). Nevertheless, sports science literature has quite neglected the possible use of this potentially useful explosive exercise for training purposes when various studies suggest that sprint training could lead to improvements in human muscle power capabilities (Malisoux et al., 2005) and dynamic athletic performance in both concentric and SSC muscle function (Markovic et al., 2007). Additionally, repeated sprints have been reported to be more efficient at improving short-sprint performance than methods such as PT (Taylor et al., 2015). Yet, soccer coaches still do not often use the SIT or strength training as they may find it quite distant from their specific activity and/or too demanding in preseason.

In fact, due to the professionalization of sport that has led to a sharp increase in the number of competitions while reducing training and recovery times (Issurin, 2008, 2010), coaches progressively left out those traditional running-based conditional exercises inspired by track and field training methods (Moran et al., 2019) to focus on more ecological methods but equally effective on fitness and football-specific performance (Hill-Haas et al., 2011; Bujalance-Moreno and Garc-a-Pinillos, 2017) such as small-sided games (SSGs). Those SSGs reproduce on a smaller scale of all the aspects of soccer that are required during competitions (Clemente and Sarmento, 2020; Clemente et al., 2020, Younesi et al., 2021). They encompass the psychological, physical, technical, and tactical aspects of the game (Clemente et al., 2012) and thus are much more accepted by soccer players (Jastrzebski et al., 2014). Moreover, recent studies reported strong relationships between traditional aerobic fitness tests with external and internal training load measures during SSGs (Stevens et al., 2016; Owen et al., 2020). Nevertheless, other authors suggested that SSGs themselves may not be enough to promote the same patterns of the required physical demands during a soccer match, mainly due to the reduced frequency of

TABLE 1 | Characteristics of the participants.

Group	Participants (n)	Age (years)	Mass (kg)	Height (m)	Maximal aerobic speed (km.h^{-1})
SSGs	24	19.3 ± 5.1	67.9 ± 8.6	1.77 ± 0.07	14.3 ± 1.1
PT	23	19.5 ± 4.0	68.1 ± 7.5	1.77 ± 0.06	14.7 ± 1.2
SIT	26	19.2 ± 3.7	67.7 ± 7.1	1.76 ± 0.06	14.4 ± 1.0

SSGs, small-sided games; PT, plyometric training; SIT, sprint interval training.

high-intensity distance-based metrics of this training approach (Lacome et al., 2017; Younesi et al., 2021). For instance, Hoff and Helgerud (2004) showed that the most skilled the players are, the lower the aerobic fitness adaptations will be elicited by SSGs. Conversely, SSGs can also be counterproductive for less-skilled players as they may not be able to consistently sustain the technical skill or tactical proficiency to achieve and maintain the required metabolic strain (Castagna et al., 2004). Moreover, Casamichana et al. (2012) reported a low number of sprints performed during SSGs combined with high volumes of aerobic stimuli. This can result in an acute reduction in sprint velocity (Katis and Kellis, 2009) or no improvements in sprint ability (Hill-Haas et al., 2009) after the use of SSGs as the conditioning strategy.

Rampinini et al. (2007a, 2011) characterized soccer as an intermittent activity where brief bouts of high-intensity running are interspersed with longer periods of low-intensity exercise. In other words, when pursuing performance in soccer, speed, power, and aerobic fitness are intimately linked and need to be all upgraded. Therefore, the aim of this study was to compare the effects on physical performance of the three different approaches (i.e., PT, SIT, and SSGs) performed in the field in recreationally trained soccer players. We hypothesized that soccer players would differently beneficiate from the different types of training, being SIT the most impactful in the measured variables.

METHODS

Athletes

Seventy-three recreationally trained soccer players (3–4 soccer training sessions per week) volunteered to take part in the experiment. Participants were randomly assigned to one of the three training groups, namely, PT, SIT, and SSGs. Mean (±SD) age, height, and maximal aerobic speed (MAS) are presented in **Table 1**. As those interventions were planned during the preseason, none of the players performed intense training (intermittent or not) during the month preceding this intervention. All training was included in addition to their usual soccer training program. The Universities Ethics Board and Human Research Ethics Committee approved this study (IRBN1042020/CHUSTE), and following a routine medical screening, participants were informed of the procedures to be employed and the associated risks and benefits of the intervention. An institutionally approved written consent form was provided and signed by all participants before any training or testing.

Experimental Protocol

The experimental design included a familiarization procedure, pretests, 3 weeks of training (PT, SIT, or SSGs), and post-tests. Before each test and training session, participants completed a standardized warm-up consisting of light to medium muscular contractions (3 sets of 10 repetitions on knee extensors and knee flexors) and three sets of 25-m progressive runs (60, 70, and 80% of the maximal sprint speed). All familiarization, testing, and training sessions were conducted in the afternoon (5–7 P.M.) to avoid performance fluctuations due to circadian rhythms. Participants were encouraged to drink water before, during, and after each testing and training session. All participants were instructed not to deviate from their current, dietary habits, or hydration patterns throughout the duration of this study. They were asked to refrain from any other kind of exercise during the experiment.

Familiarization Procedures

Before taking part in any experimental trial (baseline measurements), all subjects performed familiarization trials to become oriented with all testing procedures. The familiarization also consisted of two to three maximal bouts of 30-s shuttle runs with 4 min of recovery between bouts.

Pre- and Post-Testing

Baseline measurements for all subjects consisted of a repeated sprint ability (RSA) test (**Figure 1A**), and 48 h after, a maximal sprint speed test over 30 m (**Figure 1B**), and a MAS test (**Figure 1C**) interspersed by 20-min recovery. An experienced strength and conditioning coach supervised each test session and provided participants with strong verbal encouragement.

RSA Test

On a soccer pitch, each line was materialized by placing markers 5 m from each other for a total of 30 m (**Figure 1A**). Based on Koral et al. (2018), participants were asked to perform four bouts of 30 s all-out shuttle sprints during which they had to travel the greatest distance possible making trips of 5, 10, 15 m, and so on (**Figure 1A**). A 4-min recovery was fixed between each bout. All sprints were recorded with an iPhone 7 plus (Apple, 2017) mounted to a tripod at 240 Hz. Based on Romero-Franco et al. (2017), the iPhone was placed in a fixed position at 18 m from the pitch in the frontal plane and at the 15 m marker. The following two variables were obtained for each test session:

1) Maximal distance (D_{max}): the longest total distance covered in a 30-s period.

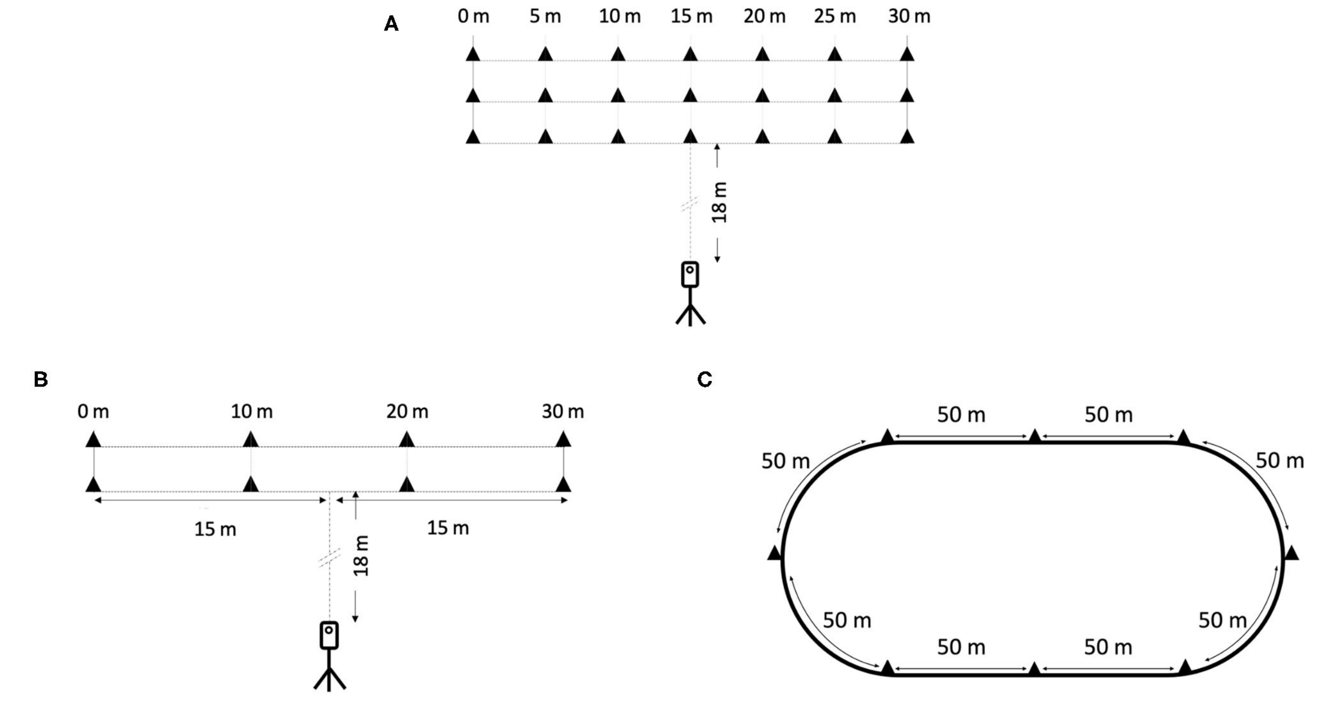

FIGURE 1 | Representation of testing protocol (PRE and POST). **(A)** Repeated sprint ability test, **(B)** maximal sprint speed test, and **(C)** maximal aerobic speed test.

2) Mean distance (D_{mean}): the total distance of the session divided by the number of repetitions: $D_{mean} = (D_{max1} + D_{max2} + D_{max3} + D_{max4})/4$.

Maximal Sprint Speed Test

Participants were supervised and instructed to run as fast as possible over 30 m on a flat soccer pitch. They performed two 30-m sprints with 5-min rest. Markers were placed every 10 m (from 0 to 30 m). All sprints were recorded with an iPhone 7 plus (Apple, 2017) mounted to a tripod at 240 Hz. The iPhone was placed in a fixed position at 18 m from the track in the frontal plane and at 15 m from both starting and finishing lines (**Figure 1B**). Based on Romero-Franco et al. (2017), video parallax was corrected to ensure 10, 20, and 30 m split times were measured properly. Data were analyzed using the application *MySprint*, in which validity and reliability have been demonstrated (Romero-Franco et al., 2017) to determine the average speed from 0 to 10 m (V_{0-10m}), and the maximal sprint speed reached during the 30-m trip (V_{max}) which was determined as the fastest 10 m interval.

MAS Test

A continuous running multistage field test, known as the "University of Montreal Track Test" (Léger and Boucher, 1980), was utilized. This protocol was run on a 400-m flat running track, with markers located every 50 m along the track (**Figure 1C**). No warm-up was performed before the test, and the speed of the initial stage was set at 8 km·h^{-1} and increased by 1 km·h^{-1} every 2 min. The speed changes were indicated by audio cues from a prerecorded audio file. The test ceased when the subject fell 5 m short of the designated markers, or when the subject reached volitional failure. The validity and reliability of this test are well-established (Léger and Boucher, 1980).

Training Period

The training period started 2 days after baseline testing. Two weekly sessions were performed by each group (i.e., SSGs, PT, and SIT) within their usual soccer training on Mondays and Wednesdays, whereas Fridays were only dedicated to soccer. The total time of the training session (training condition + soccer or only soccer) varied from 90 to 100 min.

SSGs

Participants did a standard preseason based on SSGs on the field. Those SSGs were programmed with smaller fields and less players than during a traditional soccer game. Based on Rampinini et al. (2007b), SSGs were played with no goalkeepers, small goals, and free touches. In order to increase the training load in SSGs, the pitch area moved from large (1,728 m^2) to small (480 m^2), and the number of players was also reduced each week altering, therefore, the difficulty of the technical-tactical task. The training protocol of week 1 consisted of four sets of 4 min with 3 min of passive recovery between sets. In week 2, the number of sets was increased from 4 to 5. And in week 3, the time of work was extended from 4 to 5 min. The organization, modulations, and contents of the 3-week training period are presented in **Table 2**.

PT

Participants had to perform five different kinds of exercises over the 3-week PT, namely, vertical jumps, squat jumps,

TABLE 2 | Small-sided game-specific soccer training program distribution over the 3-week training.

Week	Session	Game design	Training prescription	Inter sets passive rest	Total session time	Pitch dimensions (m)
1	1	6 vs. 6	4 × 4 min	3 min	28 min	36 x 48
	2	6 vs. 6	4 × 4 min	3 min	28 min	36 x 48
2	3	4 vs. 4	5 × 4 min	3 min	32 min	30 x 34
	4	4 vs. 4	5 × 4 min	3 min	32 min	30 x 34
3	5	3 vs. 3	5 × 5 min	3 min	37 min	24 x 20
	6	3 vs. 3	5 × 5 min	3 min	37 min	24 x 20

TABLE 3 | Plyometric training program distribution over the 3-week training.

Week	Session	Exercises					Rest between sets & exercises (min)	Total session time (min)
		Vertical jumps	Squat jumps	Counter movement jumps	Horizontal squats on sled	Drop jumps		
1	1	3 x 5 on 40 cm box	3 x 5 at BW	3 x 5 at BW	-	3 x 3 from 20 cm at BW	2	~30
	2	3 x 5 on 40 cm box	3 x 5 with SB	-	3 x 5	3 x 3 from 20 cm at BW	2	~30
2	3	3 x 5 on 40 cm box	3 x 5 with SB	-	3 x 5 assisted with EB	3 x 3 from 20 cm at BW	2	~30
	4	4 x 5 on 40 cm box	4 x 5 at BW	4 x 5 at BW	-	4 x 3 from 20 cm at BW	2	~35
3	5	4 x 5 on 40 cm box	4 x 5 with SB	-	4 x 5	4 x 3 from 20 cm at BW	2	~35
	6	4 x 5 on 40 cm box	4 x 5 with SB	-	4 x 5 assisted with EB	4 x 3 from 20 cm at BW	2	~35

BW, bodyweight; EB, elastic band; SB, Swiss ball.

countermovement jumps, horizontal squats on a sled (with or without the help of elastic bands), and drop jumps (**Table 3**). During the first three sessions, participants did three sets of five repetitions by exercise and went up to four sets of five repetitions in the last three sessions. Due to the high impacts generated during the drop jumps, the total load was lowered to three sets of three repetitions in sessions 1–3 and four sets of three repetitions in sessions 4–6 compared with the other exercises (**Table 3**). Vertical jumps and squat jumps were used to enhance the concentric muscle function when countermovement jumps and drop jumps were introduced to improve the SSC muscle function. The inclusion of a Swiss-ball in squat jumps and a sledge (assisted or not with an elastic band) in the horizontal squat during sessions 3–6 were proposed to exacerbate the velocity of each repetition by reducing the body weight (Samozino et al., 2018).

TABLE 4 | Sprint interval training distribution over 3 weeks.

Week	Session	Number of sprints	Training sprint time (min)	Total session time (min)
1	1	4	2	14
	2	5	2.5	18.5
2	3	6	3	23
	4	6	3	23
3	5	7	3.5	27.5
	6	4	2	14
	Total	32	16	110

SIT

Following the distribution of the RSA test, the soccer pitch was divided by placing markers every 5 m and up to 30 m (**Figure 1A**). Each training session consisted of repeated 30 s of "all-out" shuttle run efforts interspersed by a period of 4-min of rest (**Table 4**). Regarding the RSA test, the instructions were to travel the greatest distance possible in 30 s making trips of 5, 10, 15 m, etc. SIT volume progressively increased from 4 to 7 bouts over the first five sessions and was reduced to four bouts in the last session (**Table 4**). Participants received strong verbal encouragement to continue running maximally without pacing throughout the 30 s bouts. Up to six players performed SIT simultaneously and, during the 4-min recovery period, they walked back to the start line where they waited for the following repetitions.

Statistical Analysis

Data are presented as mean values ± SD in the text, tables, and figures and were analyzed using the STATISTICA 2007 version 8.0. (StatSoft, Inc., Tulsa, OK, USA) software. The normality assumption was verified using Shapiro-Wilk's test. In this study, the performance-related variables studied were analyzed using a two-factor mixed model design ANOVA to test the effect of the training along the time and the effect of each type of intervention on the participants (time × condition). Neuman-Keuls *post-hoc* was performed to determine between means differences if the ANOVA revealed a significant main effect or an interaction. The significance level was set at $p < 0.05$. Finally, the effect size was calculated using the partial eta square (η^2p). Criteria for evaluating the effect size were 0.01 = small, 0.06 = medium, and 0.14 = large (Cohen, 1988).

RESULTS

All individual mean PRE-POST changes are reported in **Figure 2**. All individual raw data, descriptive statistics, and effects are presented in **Table 5**.

$V_{0-10\ m}$

There was a significant loss of speed for the SSG group (−4 ± 5%; $p < 0.001$) when a statistical improvement was found in the SIT group (8 ± 5%; $p < 0.001$). No statistical changes were seen in the PT group (1 ± 6%; $p = 0.835$). A time × condition interaction was observed ($p < 0.001$; $\eta^2 p = 0.47$) for V_{0-10m} where the SSG group was significantly lower from PT and SIT groups in POST ($p < 0.001$).

V_{max}

Only slight and non-significant changes were obtained in V_{max} for SSG and SIT groups. In contrast, V_{max} significantly decreased in the PT group (−2 ± 4%; $p < 0.05$). V_{max} showed a time × condition interaction ($p < 0.05$; η^2p = 0.12) where the SSG group was significantly different from PT and SIT groups in POST ($p <$ 0.05 and $p < 0.01$, respectively).

D_{max}

No statistical differences were observed in P_{max} for the PT group. There was a significant decrease for the SSG group (−3 ± 6%; $p < 0.01$), while the SIT group showed significant improvement with 6% ± 5% ($p < 0.001$). An interaction time × condition was observed ($p < 0.001$; $\eta^2 p = 0.38$) for P_{max} where SSGs group was significantly different from PT and SIT groups in POST ($p < 0.001$).

D_{mean}

There was no significant change for the SSG group (0 ± 5%; $p = 0.89$). In contrast, both PT and SIT groups showed statistical improvements (5 ± 4 and 7 ± 5%, respectively; $p < 0.001$). In P_{mean}, a time × condition interaction was observed ($p < 0.001$; $\eta^2 p = 0.34$) where the SSG group was significantly lower from PT ($p < 0.01$) and SIT ($p < 0.001$) groups in POST. In addition, PT and SIT groups were also different in POST ($p < 0.001$).

MAS

A significant increase in MAS was observed for both PT (7 ± 6%; $p < 0.01$) and SIT (12 ± 8%; $p < 0.001$) groups when SSGs registered a significant decrease (−3 ± 6%; $p < 0.001$). An interaction time × condition was observed ($p < 0.001$; $\eta^2 p =$ 0.52) in MAS where (i) the SSG group was significantly different from PT and SIT groups in POST ($p < 0.001$) and (ii) PT and SIT groups were also different in POST ($p < 0.001$).

DISCUSSION

This study demonstrated that PT and SIT improved athletic performance when SSGs did not. More specifically, SIT significantly improved athletic performance (e.g., V_{0-10m}, D_{max}, D_{mean}, and MAS) while PT did not reach such a high impact, and SSGs showed no statistical increases. In fact and contrary to the literature (Impellizzeri et al., 2006; Dellal et al., 2012a; Kunz et al., 2019), the statistical changes in the SSG group were only losses in V_{0-10m} (−4%), P_{max} (−3%), and MAS (−3%).

Speed

Our results are in line with Bujalance-Moreno and Garc-a-Pinillos (2017), Jastrzebski et al. (2014), and Hill-Haas et al. (2009) as SIT and SSG training did not affect V_{max} but in contrast with Chaouachi et al. (2014) who reported a significant increase in V_{max} in both sprints and SSG groups. On shorter distance (i.e., V_{0-10m}), Chaouachi et al. (2014) also obtained significant improvements after the sprint and SSG training when we found an increase in the SIT group (8%, $p < 0.001$) and a decrease in the SSG group (−4%, $p < 0.001$) where both groups were significantly different in POST. As Bujalance-Moreno et al. (2019) indicated that soccer players could perform up to 250 brief explosive actions during a game, it seems more important to focus on an increase of V_{0-10m} rather than V_{max} which would be reached very occasionally during the game. Thus, the results obtained in the PT group (loss in V_{max} with no changes in V_{0-10m}) are in accordance with the SSG group in which V_{max} did not change but V_{0-10m} decreased. Additionally, SIT seems to offer the best compromise with no change in V_{max} in POST and a significant increase of $V_{0-10\ m}$.

RSA

Improvements in sprint performance (see results) and RSA have been identified as determinant factors of team sports (Reilly et al., 2009; Buchheit et al., 2010; Bujalance-Moreno et al., 2019). Rampinini et al. (2009) even suggested that the ability to complete repeated sprints could be one of the best physical factors differentiating the playing level in soccer players. Despite increases that were reported in previous studies after 2–6 weeks of SSG training (Owen et al., 2012; Bujalance-Moreno and Garc-a-Pinillos, 2017; Rodríguez-Fernández et al., 2017), in this study, and as for speed, SSGs had no effect on D_{mean} and negatively affected D_{max} (−3%). It is important to notice that those results were significantly different from PT and SIT groups where PT presented no change in D_{max} (1%) and statistical improvements in D_{mean} (5%). Once again, SIT exhibited the highest increase in both D_{max} (6%) and

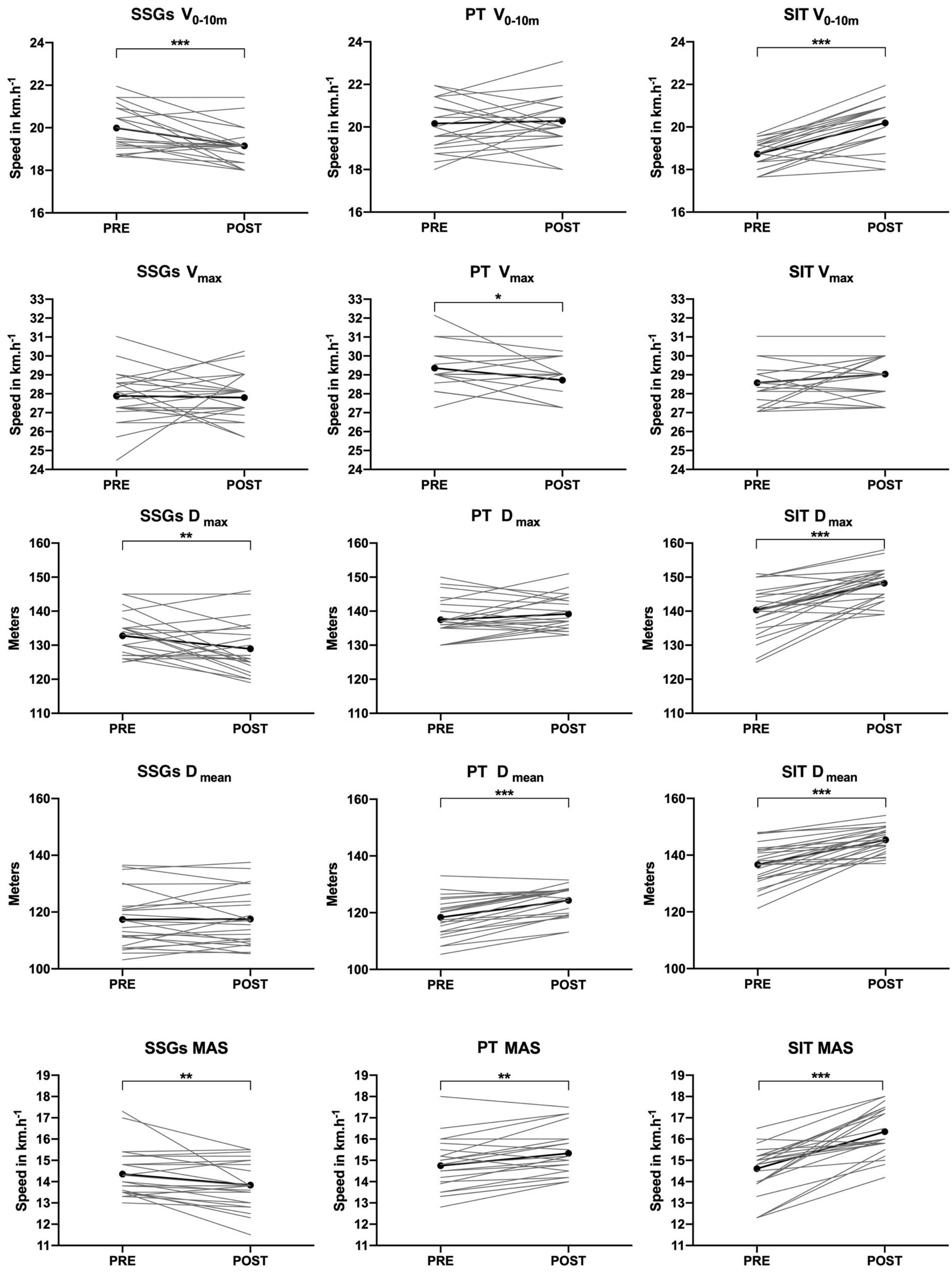

FIGURE 2 | Individuals and mean PRE-POST variations in all parameters. SSGs, small-sided games; PT, plyometric training; SIT, sprint interval training. V_{0-10m}: maximal speed from 0 to 10 m; V_{max}: maximal sprint speed reached during the 30-m trip; P_{max}: peak power output; P_{mean}: mean power output; MAS: maximal aerobic speed. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

TABLE 5 | Raw data, descriptive statistics, and effects by groups.

Descriptive statistics	**Pre ± SD**	**Post ± SD**	**Mean difference**			
V_{0-10} (km.h^{-1})						
SIT	18.728 ± 0.631	20.190 ± 1.047	1.462			
PT	20.163 ±1.095	20.285 ± 1.057	0.122			
SSGs	19.994 ± 1.008	19.150 ± 0.874	−0.844			
Effects	Sum of Squares	df	Mean Square	F	P	η^2p
Time	2.220	1	2.220	4.020	0.049	0.054
Time x Condition	33.576	2	16.788	16.788	<0.001	0.465
Condition	16.235	2	8.117	6.273	<0.003	0.152
V_{max} (km.h^{-1})						
Descriptive statistics	Pre ± SD	Post ± SD	Mean difference			
SIT	28.582 ± 1.106	29.045 ± 1.216	0.463			
PT	29.35 ± 1.086	28.722 ± 1.141	−0.636			
SSGs	27.889 ± 1.380	27.804 ± 1.215	−0.085			
Effects	Sum of Squares	df	Mean Square	F	P	η^2p
Time	0.270	1	0.270	0.335	0.565	0.005
Time x Condition	7.386	2	3.693	4.576	0.014	0.016
Condition	38.356	2	19.178	9.365	<0.001	0.211
MAS (km.h^{-1})						
Descriptive statistics	Pre ± SD	Post ± SD	Mean difference			
SIT	14.612 ± 1.102	16.354 ± 1.054	1.742			
PT	14.748 ± 1.216	15.330 ± 1.086	0.582			
SSGs	14.358 ± 1.131	13.842 ± 1.091	−0.516			
Effects	Sum of Squares	df	Mean Square	F	P	η^2p
Time	133.598	1	133.598	133.598	0.013	0.085
Time x Condition	859.325	2	859.325	859.325	<0.001	0.375
Condition	4526.524	2	2263.262	39.732	<0.001	0.532
D_{max} (m)						
Descriptive statistics	Pre ± SD	Post ± SD	Mean difference			
SIT	140.346 ± 7.250	148.231 ± 7.506	7.885			
PT	137.478 ± 5.907	139.174 ± 4.969	1.696			
SSGs	132.750 ± 6.187	128.917 ± 4.966	−3.653			
Effects	Sum of Squares	df	Mean Square	F	P	η^2p
Time	133.598	1	133.598	6.538	0.013	0.085
Time x Condition	859.325	2	429.663	21.026	<0.001	0.375
Condition	4526.524	2	2263.262	39.732	<0.001	0.532
D_{mean} (m)						
Descriptive statistics	Pre ± SD	Post ± SD	Mean difference			
SIT	136.692 ± 6.981	145.385 ± 4.464	8.693			
PT	118.370 ± 6.941	124.347 ± 5.332	5.977			
SSGs	117.369 ± 10.029	117.506 ± 9.869	0,137			
Effects	Sum of Squares	df	Mean Square	F	P	η^2p
Time	886.902	1	886.902	67.567	<0.001	0.491
Time x Condition	471.980	2	235.990	17.978	<0.001	0.339
Condition	16100.584	2	8050.292	80.086	<0.001	0.696

SIT, sprint interval training; TG, plyometric training; SSGs, small-sided games.

D_{mean} (7%). Nonetheless, SIT enhancements were in the lower part of the bulk of the literature on 2–4 week SIT which experienced a 5–17% improvement in D_{max} and a 4–17% in D_{mean} (Burgomaster et al., 2005, 2006; Hazell et al., 2010; Whyte et al., 2010; Bayati et al., 2011; Willoughby et al., 2016). Besides the previously discussed differences in subject training experience, it is important to notice that this study performed tests and training on the field, which do not allow for the same level of accuracy as direct measures of power on a cycle ergometer.

MAS

Maximal aerobic speed in the SIT group improved significantly by 12% following the 3-week intervention. The PT group also progressed (7%, $p < 0.01$) but slightly less than the SIT group. Compared with the literature that utilized a 2–4-week SIT intervention period (−2 to 9.5% Burgomaster et al., 2006; Iaia et al., 2009; Hazell et al., 2010; Whyte et al., 2010; Bayati et al., 2011; Astorino et al., 2012; Denham et al., 2015; Willoughby et al., 2016), the results of this study are higher. Furthermore, these studies were conducted in untrained or active subjects, and our results are then even more valuable since our participants were already trained soccer players. Potentially, this type of training could have enhanced neuromuscular capacity in soccer players as supported by the improvements obtained in D_{max} and D_{mean} (see results). It can be assumed that the PT group which also increased both MAS and D_{mean} may share part of the adaptive mechanisms. Those may result in a better running economy and therefore higher performances (Helgerud et al., 2001; Rowan et al., 2012). Interestingly, the SSG group presented a significant decrease in MAS (−3%, $p < 0.001$). As players were not wearing any GPS system associated with a heartbeat monitor, the internal training load could not be quantified. Nevertheless, it can be speculated that the technical-tactical level of the players was not good enough to deal with the SSGs proposed by coaches (Dellal et al., 2011, 2012b). Consequently, as proposed by Castagna et al. (2004), players were not able to maintain the required metabolic strain even if the coaches chose SSGs involving possession in which heart rate was supposed to be higher (Castellano et al., 2013). Moreover, contrary to Rampinini et al. (2007b), the 3-min recovery between sets during SSG sessions was passive. This may also have participated to lower much of the metabolic strain. In line with Bujalance-Moreno et al. (2019), another hypothesis is that contrary to SIT and PT, two sessions of SSGs per week over 3 weeks were not enough to develop any change in players or as in our case lead to a significant decrease.

However, players require well-developed aerobic endurance to maintain intense levels of activity and to limit fatigue at the same time (Köklö et al., 2015). Furthermore, improvement in MAS allows for greater involvement with the ball, total distance covered, and an increase in the number of sprints performed during match play (Radziminski et al., 2013). Developing MAS still is one of the main objectives in soccer, and this study highlighted SIT as a very adequate method.

Limitations

As this study was intentionally field-related, direct measures of VO_{2max} and heart rate were not performed so that the internal load could not be assessed. This is a potential limitation when trying to explain some of the results found notably in the SSG group.

Another point is that even if PT and SIT enhanced the performance in speed, RSA, and MAS, it can only be speculated that participants of PT and SIT groups will be more efficient during a real soccer game. Objectively, it would be hard to determine (i) if those 3–12% improvements depending on the parameter and the training group (PT or SIT) will have a real impact on a game situation, and (ii) what would be the magnitude of real competitive effects due to those improvements.

It could also be speculated that with a longer training time (i.e., 4–6 weeks) and a higher frequency (three times per week), PT would give results that would be closer to SIT.

Moreover, since the SIT group performed training sessions that were close to the RSA testing procedure, the number of repetitions achieved during SIT sessions might have positively influenced the performance in D_{max} and D_{mean}.

Finally, the results reported, in this study, can also be a reflection of faster adaptations in one training compared with the others as it is now well-admitted that adaptations induced by the different training methods require a different amount of time to appear. Future studies should consider this parameter and program different post-testing sessions (i.e., 1 and 2 weeks after the first post-tests).

Practical Applications

Overall, all performance parameters presented a time × condition interaction where the SSG group was significantly different from PT and SIT groups in POST. More specifically, those interactions expressed significant opposite evolutions where SIT and PT maximized performance parameters where SSGs tended to diminish them. Moreover, they also suggest that SIT seems to be more efficient than PT when attempting to improve D_{mean} and MAS.

As a result and contrary to the literature, SSGs, even though they could have some positive aspects on physical performance, should not be considered as a training method but mainly as a way to improve technical-tactical aspects. In this precise case, it is possible that the principle of specificity as defined by Reilly et al. (2009) would not allow reaching maximum benefits. Effectively, if SSGs are very similar to the conditions of a soccer match, they do not always simulate the high-intensity efforts and repeated sprints that the full game demands (Casamichana et al., 2012).

CONCLUSION

As modern coaches must constantly deal with an increasingly congested fixture period of competitions which subsequently reduces the preparation time available, the results of this study demonstrate that SIT could be a more efficient alternative than SSGs and PT when aiming to enhance both endurance and anaerobic performances in preseason. In addition, as the ability to complete repeated sprints could be one of the best physical factors differentiating the playing level in soccer players, SIT could be used as an efficient training and as a testing method indifferently.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by French Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JK contributed to the conception, design of this study, and drafted the manuscript. FLR collected the data. JK, JLV, FLR, and CF contributed to the analysis and interpretation of the data. JLV, FLR, and CF critically revised the manuscript. All authors gave final approval and agreed to be accountable for all aspects of work ensuring integrity and accuracy.

ACKNOWLEDGMENTS

The authors would like to thank the department of clinical and exercise physiology (Myology and Sports Medicine Unit) of the University Hospital of Saint-Etienne for logisitcal support.

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frontiers
in Sports and Active Living

BRIEF RESEARCH REPORT
published: 11 October 2021
doi: 10.3389/fspor.2021.757253

Check for updates

Seasonal Changes and Relationships in Training Loads, Neuromuscular Performance, and Recovery and Stress State in Competitive Female Soccer Players

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OPEN ACCESS

Edited by:
Damiano Formenti,
University of Insubria, Italy

Reviewed by:
Luca Paolo Ardigò,
University of Verona, Italy
Hadi Nobari,
University of Granada, Spain

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Sports and Active Living

Received: *11 August 2021*
Accepted: *07 September 2021*
Published: *11 October 2021*

Citation:
Ishida A, Bazyler CD, Sayers AL, Stone MH and Gentles JA (2021) Seasonal Changes and Relationships in Training Loads, Neuromuscular Performance, and Recovery and Stress State in Competitive Female Soccer Players. Front. Sports Act. Living 3:757253. doi: 10.3389/fspor.2021.757253

Background: The purpose of this study was to examine seasonal changes in training load (TL), neuromuscular performance, subjective recovery, and stress state, and to investigate the relationships between acute and chronic TL and neuromuscular performance in competitive female soccer players.

Methods: Nine competitive female soccer players (20.0 ± 1.7 years; 60.3 ± 6.3 kg; 164.0 ± 5.8 cm) completed the Short Recovery and Stress Scale and the countermovement jump (CMJ) with polyvinyl chloride pipe (CMJ0) and 20 kg barbell (CMJ20) at 2–3 h before 1st match (NC_1), 6th match (NC_2), 9th match (C_1), and 15th match (C_2) of the competitive season. TL included total distance, high-speed running, and PlayerLoad. Acute and chronic TL was calculated by using the average of 2 days (D_2), 7 days (D_7), and 21 days (D_{21}) prior to four different match play.

Results: Significant decreases were found from NC_1 to C_1 in D_7 total distance [$p = 0.03$, Cohen's effect size (d_z) = 1.40]. D_7 total distance and PlayerLoad significantly decreased from NC to C_1 and C_2 (p = 0.001–0.01, d_z = 1.40–1.72). Significant increases were observed from NC_1 to C_1 in CMJ0 jump height ($p = 0.03$, $d_z = 1.40$), ($p = 0.021$, $d_z = 1.44$), and peak power ($p = 0.03$, $d_z = 1.32$). Significant negative correlations were observed for D_7 total distance and CMJ0 jump height ($p = 0.02$, $r = 0.79$) and peak power ($p = 0.03$, $r = 0.71$) at C_2, while significant positive correlations were observed at C_1 for D_7 PlayerLoad and CMJ0 jump height ($p = 0.02$, $r = 0.80$).

Conclusion: Polyvinyl chloride pipe **(**CMJ0) jump height and peak power may increase from preseason to the midcompetitive season. Seasonal variations may affect the relationships between D_7 TL and CMJ0 performance.

Keywords: fatigue, performance, team sport, power, athlete monitoring

INTRODUCTION

Soccer is an intermittent sport consisting of walking, running, sprinting, and changing of direction, kicking, and heading for 90 min (Stølen et al., 2005). Due to the physical demands of the match, the practitioners (e.g., sports coaches, strength and conditioning coaches, sports scientists) require long-term strategic training plans to gradually accumulate training load (TL) and to develop physical capacity of the players during a pre-season (Stølen et al., 2005). However, it may be difficult to improve the physical capacity of the players during this period for the National Collegiate Athletic Association (NCAA) soccer. The NCAA soccer schedule allows only 2 to 3 weeks of pre-season training followed by 12 to 16 weeks of the competitive season (Sams et al., 2018, 2020; Walker et al., 2019; McFadden et al., 2020). As a result, the NCAA coaching staff often plans higher TLs during pre-season compared to the competitive season (McFadden et al., 2020), which increases the risk of injuries (Agel and Schisel, 2013), psychological stress, and physiological damage (Walker et al., 2019). In addition, the NCAA restricts players from reporting their training to the coaching staff during the summer break (May–July) and evidence indicates that players accumulate limited TL during this period (Sams et al., 2018, 2020; Walker et al., 2019; McFadden et al., 2020). Therefore, the lack of training in the summer often results in a short, high volume pre-season preparation at the NCAA soccer, increasing injuries, and compromising the physical and psychological preparation of the player for the competitive season (Eckard et al., 2018).

Integration of an athlete monitoring program would be useful to develop physical and psychological preparation of the player in NCAA soccer. Athlete monitoring programs primarily aim to maximize sports performance and improve program efficacy while minimize fatigue during the competitive season (Ishida et al., 2021b). Specifically, one aspect of an athlete monitoring program is aimed at quantifying dose-response relationships in order to manage fatigue and to improve training efficacy during the competitive season (Halson, 2014; Gabbett et al., 2017). The monitoring data can inform the practitioners about a current physical and psychological state of the player and assist their decision-making for TL management. Common measures of an athlete monitoring program, particularly for fatigue management, include the Global Navigation Satellite System (GNSS), subjective recovery and stress state, and the countermovement jump (CMJ) (Sams et al., 2018; Travis et al., 2018, 2020; Walker et al., 2019; McFadden et al., 2020; Draper et al., 2021; Ishida et al., 2021c). The GNSS devices have been used to quantify external TL, including the TL of soccer match play, which have been associated with acute muscle damage and the alterations in neuromuscular performance (de Hoyo et al., 2016; Russell et al., 2016; Coppalle et al., 2019; Wiig et al., 2019; Ishida et al., 2021a). Ishida et al. (2021b) reported the strong negative correlations between the changes in loaded CMJ, peak power (PP), and total running distance ($p = 0.02$, $r = 0.65$) at 12 h post-match in the NCAA female soccer players. Therefore, the assessment and manipulation of TL using GNSS can be beneficial for maximizing neuromuscular performance.

Measures of subjective recovery and stress state and CMJ are common monitoring tools to quantify the response to TL. The combined use of these measures with GNSS allows for quantifying a dose–response relationship (Halson, 2014; Impellizzeri et al., 2019; Draper et al., 2021; Ishida et al., 2021b). The Short Recovery and Stress Scale (SRSS) is a reliable questionnaire (Kellmann and Kölling, 2019) and consists of eight subscales including physical performance capability (PPC), mental performance capability (MPC), emotional balance (EB), overall recovery (OR), muscular stress (MS), lack of activation (LA), negative emotional state (NES), and overall stress (OS). Current literature (Wiewelhove et al., 2016; Hitzschke et al., 2017; Pelka et al., 2018; Travis et al., 2020) has shown that the SRSS scales are reflective of acute high TLs. The CMJ is also an easy and reliable measure to assess the neuromuscular performance in female soccer players (Andersson et al., 2008; Nedelec et al., 2014; de Hoyo et al., 2016; Claudino et al., 2017). Current evidence also indicates that CMJ performance alternations can be affected by TL and are associated with neuromuscular and physiological damage (Andersson et al., 2008; de Hoyo et al., 2016; Silva et al., 2018; Hader et al., 2019). For example, Andersson et al. (2008) found that statistically significant decreases were observed in CMJ jump height with substantially increased serum creatine kinase (CK) at 21 h after a soccer match play in the elite female soccer players. Therefore, the SRSS and CMJ measure monitoring subjective and objective responses to TL that may provide a better understanding of the response to the manipulations and variations of TL.

Among the soccer players, seasonal variability of TL, physical capacity, performance, and subjective recovery and stress state should be considered. Several studies (Malone et al., 2015; Clemente et al., 2019, 2020; Nobari et al., 2021b) indicate that TL can be substantially higher during a preseason in soccer than the typical loads during the competitive season. For example, Clemente et al. (2020) reported that the weekly total distance covered was considerably higher during pre-season than the end of the competitive season in the professional male soccer players. As TL tends to decrease, physical performance tends to increase as the competitive season progresses (Dragijsky et al., 2017; Sams et al., 2018; Emmonds et al., 2020). However, seasonal variability could be problematic, particularly for quantifying the relationship between TL and the alterations of neuromuscular performance. Although the meta-analyses (Silva et al., 2018; Hader et al., 2019) showed TL is inversely related to physical performance, no investigations have been performed to quantify the relationship interacting with seasonal variability. This information would provide the practitioners with an understanding of how monitoring measures can be useful for associating neuromuscular performance and subjective recovery status with TL variations.

With respect to the NCAA female soccer season, athlete monitoring measures may be incorporated to appropriately guide physical preparation of the player from the pre-season to the end of the competitive season (Ishida et al., 2021b). Although the seasonal variations in TL and neuromuscular performance in the soccer players would occur (Dragijsky et al., 2017; Sams et al., 2018; Walker et al., 2019; Emmonds et al., 2020), few investigations have been performed as to how measures of neuromuscular performance, subjective recovery, and stress state will change across the competitive season. Therefore, the purpose of this study was to investigate as follows: (1) seasonal changes in TL, neuromuscular performance, and subjective recovery and stress state and (2) to examine the relationship between TL and neuromuscular changes in the division I collegiate female soccer players. It was hypothesized that: (1) TL, neuromuscular performance, and subjective recovery and stress state would vary and (2) negative relationships would be observed between TL and neuromuscular performance across the competitive season in the Division I collegiate female soccer players.

MATERIALS AND METHODS

Design

Data collection occurred throughout the 2019 NCAA soccer season consisting of 2 weeks of pre-season and 11 weeks of the competitive season, respectively. Data were collected by using a GNSS for TL. The average of 2 days (D_2), 7 days (D_7), and 21 days (D_{21}) GNSS TL was calculated prior to four different match play: 1st match of the competitive season (NC_1; 1st non-conference match play), 6th match-play of the competitive season (NC_2; 6th non-conference match play), 9th match of the competitive season (C_1; 1st conference match play), and 15th match of the competitive season (C_2; 6th conference match play). Neuromuscular performance and subjective recovery state were evaluated *via* the CMJ and SRSS assessments at 3 h prior to NC_1, NC_2, C_1, and C_2. Data collection at NC_1, NC_2, C_1, and C_2 were performed at the first match-play of each week.

Subjects

In this study, the NCAA division I nine female soccer players were included [age 20.0 ± 1.7 years (age range: 18–22 years); body mass 60.3 ± 6.3 kg; height 164.0 ± 5.8 cm; resistance training experience 1–4 years]. Demographic information was collected on the first day of the pre-season. The inclusion criteria for this study were as follows: (a) players were outfield players (defender, midfielder, or forward) and (b) must have completed all testing sessions. This study included six starters (played 74 to 100% of match time across all the NCAA matches) and three non-starters (played 28 to 44% of match time across all the NCAA matches). Six players were excluded from this study because they could not complete CMJ tests. Depending upon the travel schedule, the players completed 0 to 1 strength maintenance weight training sessions each week during pre-season and non-conference play (day 1–51). Weight training was performed two times per week during the conference play (day 52–82). During this study, all the participants were informed of the risks and benefits and testing procedures before participation. The participants signed informed consent and this study was approved by the University Institutional Review Board.

Training Load Measure

D_2, D_7, and D_{21} TLs were measured by using a GNSS (10 Hz) and accelerometry (triaxial; 100 Hz) units (Catapult OptimEye

TABLE 1 | Seasonal changes in training loads.

Variables	Periods				Percentage changes (d_z)		
	NC_1	NC_2	C_1	C_2	NC_1-NC_2	NC_1-C_1	NC_1-C_2
D_2							
Total distance (m)	4,108.6 ± 1,026.7	3,573.1 ± 365.1	2,638.1 ± 247.1*§	3,627.8 ± 696.5§¶	23.9 ± 19.3 (ES = 0.54)	31.9 ± 18.8 (ES = 1.53)	8.7 ± 12.0 (ES = 0.58)
HSR (m)	331.4 ± 295.4	225.9 ± 116.2	144.8 ± 68.0§	250.2 ± 128.0	34.8 ± 34.1 (ES = 0.48)	32.2 ± 88.1 (ES = 0.83)	25.9 ± 33.1 (ES = 0.29)
Total PlayerLoad (au)	491.1 ± 129.1	408.8 ± 64.0	361.9 ± 68.8*§	442.9 ± 110.6¶	10.8 ± 17.1 (ES = 0.73)	23.3 ± 20.8 (ES = 1.24)	7.2 ± 10.7 (ES = 0.43)
D_7							
Total distance (m)	4,451.9 ± 775.2	5,831.6 ± 1,534.2	3,567.7 ± 317.0*§	4,164.9 ± 1,744.2§	50.6 ± 13.7 (ES = 1.00)	18.0 ± 40.0 (ES = 1.40)	5.1 ± 33.4 (ES = 0.17)
HSR (m)	394.6 ± 180.2	416.4 ± 213.5	318.9 ± 121.1	282.6 ± 226.0	20.9 ± 24.1 (ES = 0.16)	12.3 ± 43.8 (ES = 0.75)	25.2 ± 31.7(ES = 0.55)
Total PlayerLoad (au)	520.5 ± 104.8	638.8 ± 168.0	464.5 ± 62.4§	471.8 ± 181.1	33.5 ± 10.5 (ES = 0.83)	9.2 ± 35.3 (ES = 1.03)	7.9 ± 26.2 (ES = 0.28)
D_{21}							
Total distance (m)	4,524.9 ± 713.3	5,063.4 ± 1,348.1	4,692.4 ± 1,173.8	4,717.1 ± 1,671.6	7.9 ± 32.8 (ES = 0.41)	6.0 ± 49.2 (ES = 0.14)	8.2 ± 8.5 (ES = 0.11)
Total PlayerLoad (au)	527 ± 101.6	561.6 ± 140.4	537.9 ± 138.3	532.7 ± 140.4	4.4 ± 30.0 (ES = 0.26)	4.4 ± 43.9 (ES = 0.08)	5.0 ± 7.3 (ES = 0.03)
HSR (m)	318.6 ± 139.1	365.9 ± 191.4	372.7 ± 168.7	311.5 ± 192.1	4.4 ± 22.5 (ES = 0.54)	17.2 ± 43.9 (ES = 0.72)	0.5 ± 14.5 (ES = 0.05)

d_z, Cohen's d_z effect size; NC_1, 1st non-conference match-play; NC_2, 7th non-conference match-play; C_1, 1st conference match-play; C_2, 6th conference match-play; HSR, high speed running distance. *Denotes $p \leq 0.05$ from NC_1; §denotes $p \leq 0.05$ from NC_2; ¶denotes $p \leq 0.05$ from C_1.

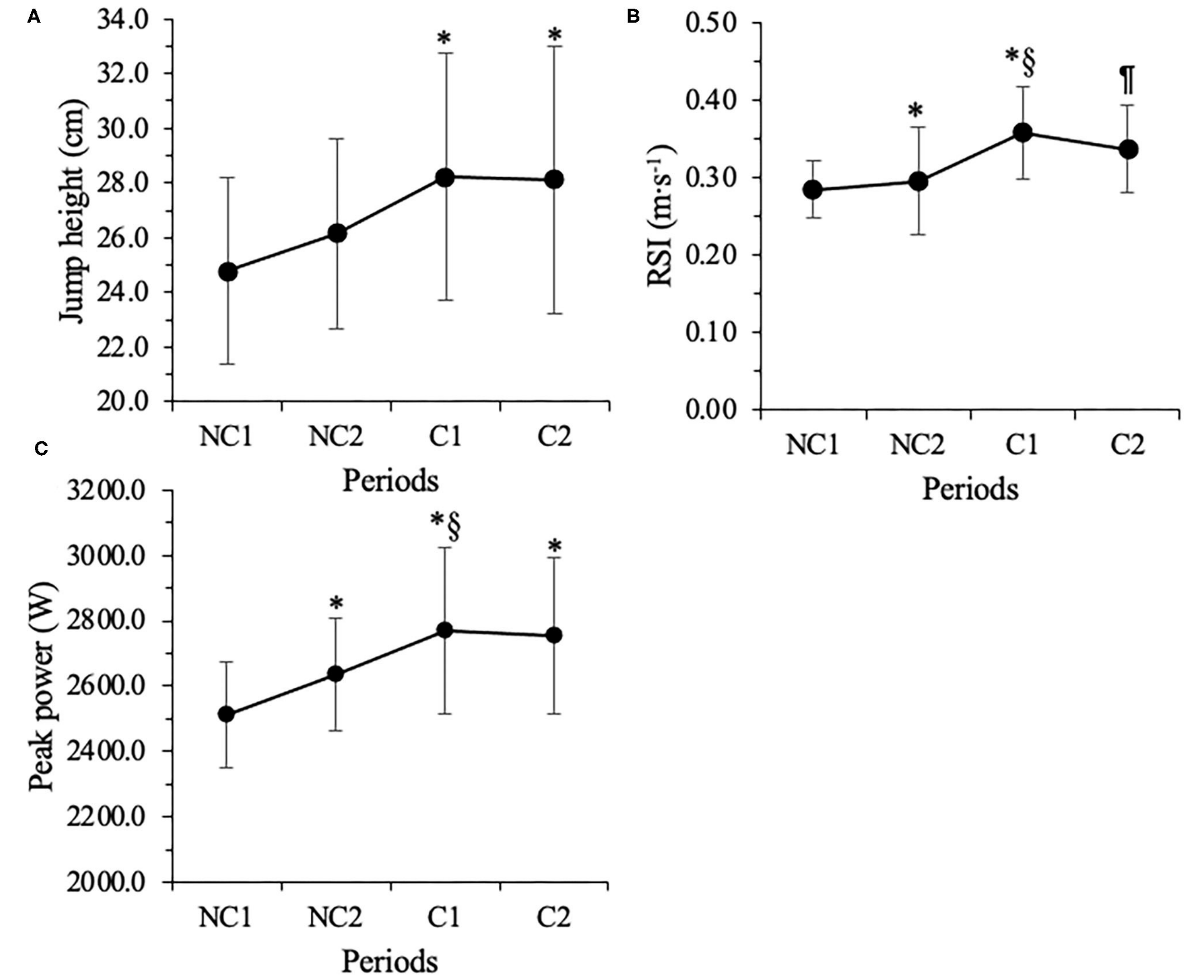

FIGURE 1 | Seasonal changes in unloaded countermovement jump height **(A)**, modified strength index (RSI) **(B)**, and peak power **(C)**. NC_1 = 1st non-conference match-play. NC_2 = 7th non-conference match-play. C_1 = 1st conference match-play. C_2 = 6th conference match-play. *Denotes $p \leq 0.05$ from NC_1. §Denotes $p \leq 0.05$ from NC. ¶Denotes $p \leq 0.05$ from C_1.

S5, Catapult Innovations, Team Sport 5.0, Melbourne, Australia). A team of sports scientists powered all the units at least 10 min before the on-field warm-up. Players wore the GNSS units in a vest, which positioned the unit between the shoulder blades. Training and match-derived TL data included the warm-up until the end of the session. Variables of interest related to training volume included total distance (m), high-speed running distance (HSR; m), and PlayerLoad (au). HSR was defined as running above 15 km h^{-1}. PlayerLoad was calculated as the square root of the sum of the squared differences of acceleration in all the three axes divided by the device sampling frequency of 100 Hz (Nicolella et al., 2018). According to the previous literature (Scott et al., 2016; Nicolella et al., 2018; Nikolaidis et al., 2018), a 10-Hz GNSS unit demonstrates good-to-moderate reliability for total distance [coefficient of variation (CV) = 1.9%] and running involving accelerations (CV = 1.9–4.3%) and PlayerLoad (CV = 0.0–3.0% in anterior-posterior, medial-lateral, and vertical axes). The average TL of 2, 7, and 21 days prior to an average match play was calculated (Carey et al., 2017; Sams et al., 2018).

Short Recovery and Stress Scale

The player recovery and stress state were used to assess the subjective recovery and stress state across the 10 week competitive season *via* the SRSS. The players completed the SRSS from an online-based application (Google Forms, Google, California, United States). All the players were fully familiarized with the procedures using a pre-season match. Prior to the SRSS, hydration status was assessed using a refractometer (ATAGO Corporation Limited, Tokyo, Japan) before the SRSS measurement. The players were considered as hydrated if specific gravity of urine was <1.020. The SRSS is rated by using a seven-point Likert scale from 0 (does not fully apply) to 6 (fully applies) and consists of eight subscales including PPC, MPC, EB, OR, MS, LA, NES, and OS. The Recovery Scale (RS) includes PPC, MPC, EB, and OR, while the Stress Scale (SS) includes MS, LA, NES, and OS. The SRSS has shown acceptable internal reliability ($\alpha = 0.74$ and $\alpha = 0.78$) (Kellmann and Kölling, 2019).

Countermovement Jump

The players completed a standardized dynamic warm-up followed by submaximal CMJs at 75% and 100% of perceived maximal efforts, respectively. The players then performed three maximal CMJ trials with a polyvinyl chloride pipe (CMJ0) and with 20 kg barbell (CMJ20) on dual portable force plates (PASPORT Force Platform, PASCO, California, United States of America) by using a sampling frequency of 1,000 Hz. Each load was held across the back on the shoulders. For the CMJ tests, the players stood still on the force plates for at least 1 s and then vertically jumped after flexing the hip, knee, and ankle joints on the command of "3, 2, 1, jump!". Approximately, a 1-min interval was provided between the CMJ0 and CMJ20 trials. After CMJ testing, the raw data were converted into a comma-separated values file and then analyzed by using a Microsoft Excel sheet (Microsoft Excel, Microsoft, Washington, United States of America) (Chavda et al., 2018). The mean of two trials with the best jump heights (JHs) was used for analysis. Body mass (BM; kg), JH from impulse (cm), modified reactive index (RSI; m s^{-1}), peak force (PF; N), relative PF (RPF; N kg^{-1}), eccentric impulse (EI; N s^{-1}), concentric impulse (CI; N s^{-1}), (PP; W), relative PP (RPP; W kg^{-1}), eccentric peak power (EPP; W), and concentric peak power (CPP; W) were included as variables of interest. The test-retest reliability of the variables was acceptable in CMJ0 [CV = 2.1–5.9%; intraclass correlation coefficient (ICC) = 0.86–0.97] and CMJ20 (CV = 2.7–6.2%; ICC = 0.76–0.92).

Statistical Analysis

All the statistical procedures were performed by using the statistical software RStudio (version 1.1.463) and the packages dplyr (0.8.5), rstatix (0.4.0), and stats (3.5.3). One-way repeated analysis of variance was conducted to examine the difference in the CMJ0 and CMJ20 kinetic variables and the TLs across the four different periods (NC_1, NC_2, C_1, and C_2). For the SRSS and the CMJ variables (JH in CMJ0 and JH and PF in CMJ20) that did not meet the assumption of normality, the Friedman test was performed to identify the differences between the periods. When necessary, *post-hoc* testing with the Bonferroni correction was performed. A Cohen's d_z effect sizes (d_z) were also calculated by using standardized mean difference and were classified as follows; $d_z < 0.2$ = trivial, $0.2 \leq d_z < 0.6$ = small, $0.6 \leq d_z < 1.2$ = moderate, $1.2 \leq d_z < 2.0$ = large, and $d_z \geq 2.0$ = very large (Hopkins et al., 2009). The Pearson coefficient correlation tests were also conducted to examine the relationship between TL and the changes from NC_1 to NC_2, C_1, and C_2 in the selected CMJ0 and CMJ20 kinetic variables (JH, RSI, PF, and PP). The correlation coefficient magnitudes were determined by using Hopkin's classification (Hopkins et al., 2009) and were classified as follows: $r < 0.10$ = trivial, $0.10 \leq r < 0.30$ = small, $0.30 \leq r < 0.50$ = moderate, $0.5 \leq r < 0.7$ = large, $0.70 \leq r < 0.90$ = very large, $0.90 \leq r < 1.00$ = nearly perfect, and 1.0 = perfect. All the data were expressed as mean ± SD. Statistical significance was set at $p \leq 0.05$.

RESULTS

Seasonal Changes in Training Loads, Countermovement Jump, Short Recovery, and Stress State

Statistically significant differences were observed between NC_1 and C_1 in D_2 total distance ($p = 0.02$, $d_z = 1.53$) and PlayerLoad ($p = 0.05$, $d_z = 1.24$). D_2 total distance and PlayerLoad were also statistically decreased from NC_2 to C_1 (total distance, $p < 0.001$, $d_z = 2.68$; PlayerLoad, $p = 0.04$, $d_z = 1.28$) and C_2 (total distance, $p = 0.05$, $d_z = 1.86$; PlayerLoad, $p = 0.03$, $d_z = 1.35$). Additionally, statistically significant differences were found from NC_1 to C_1 in D_7 total distance ($p = 0.03$, $d_z = 1.40$). D_7 total distance and PlayerLoad were statistically decreased from NC_2 to C_1 (total distance, $p = 0.03$, ES = 1.40; PlayerLoad, $p = 0.02$, $d_z = 1.72$) and C_2 (total distance, $p = 0.03$, $d_z = 1.40$; PlayerLoad, $p = 0.02$, $d_z = 1.49$) (**Table 1**). However, no statistical differences were noted for D_{21} total distance, HSR, and PlayerLoad ($p > 0.05$).

Statistically significant differences were observed from NC_1 to C_1 in CMJ0 JH ($p = 0.03$, $d_z = 1.40$), RSI ($p = 0.02$, $d_z = 1.44$), PP ($p = 0.034$, $d_z = 1.32$), and CAP ($p = 0.01$, $d_z = 1.74$) (**Figure 1**). Statistically significant differences were also noted from NC_1 to C_2 for CMJ0 JH ($p = 0.015$, $d_z = 1.53$), PP ($p = 0.01$, d_z =1.57), and RPP ($p = 0.03$, d_z =1.40). Additionally, CMJ20 JH, PP, and RPP showed statistically significant differences from NC_1 to C_2 (JH, $p = 0.019$, $d_z = 1.47$; PP, $p = 0.03$, $d_z = 1.37$; RPP, $p = 0.02$, $d_z = 1.49$). However, no statistically significant changes were seen in BM and CMJ0 and CMJ20 PF, RPF, and EAP ($p > 0.05$) (**Table 2**). No significant changes were observed in any of the SRSS items across time ($p > 0.05$).

Seasonal Relationships Between Training Loads and the Changes in Countermovement Jump Performance

Very large positive correlations were observed at C_1 between D_2 total PlayerLoad and the changes from NC_1 to C_1 in CMJ0 JH ($p = 0.05$, $r = 0.67$); D_7 total PlayerLoad and CMJ0 JH ($p = 0.02$, $r = 0.80$), RSI ($p = 0.03$, $r = 0.80$), and PF ($p = 0.02$, $r = 0.77$). In CMJ20, very large positive correlations were also found between D_2 total PlayerLoad and the changes from NC_1 to C_1 in CMJ0 JH ($p < 0.001$, $r = 0.88$), RSI ($p = 0.001$, $r = 0.86$), and PF ($p = 0.001$, $r = 0.93$); D_7 total PlayerLoad and JH ($p = 0.01$, $r = 0.87$) and PF ($p < 0.001$, $r = 0.90$). At C_2, very large negative correlations were observed between D_7 total distance and the changes from NC_1 to C_2 CMJ0 JH ($p = 0.02$, $r = 0.79$) and PP ($p = 0.03$, $r = 0.71$); D_{21} total distance and CMJ0 JH ($p = 0.04$, $r = 0.70$) and PP ($p = 0.04$, $r = 0.69$) (**Figure 2**).

TABLE 2 | Seasonal changes in unloaded and loaded countermovement jump kinetics.

					Percentage changes (d_z)		
Variables	**NC_1**	**NC_2**	**C_1**	**C_2**	**NC_1-NC_2**	**NC_1-C_1**	**NC_1-C_2**
CMJ0							
BW	62.2 ± 5.9	62.5 ± 6.1	62.5 ± 6.3	61.7 ± 5.7	0.2 ± 1.4 (ES = 0.29)	0.3 ± 1.5 (ES = 0.24)	0.7 ± 3.2 (ES = 0.26)
JH (cm)	24.8 ± 3.4	26.1 ± 3.5	28.2 ± 4.5*	28.1 ± 4.9*	8.3 ± 8.0 (ES = 0.73)	14.1 ± 11.4 (ES = 0.89)	13.3 ± 9.6 (ES = 0.85)
RSI ($m \cdot s^{-1}$)	0.28 ± 0.04	0.30 ± 0.07	0.36 ± 0.06*§	0.34 ± 0.06	22.1 ± 15.1 (ES = 0.18)	26.6 ± 21.1 (ES = 1.44)	20.8 ± 29.8 (ES = 0.72)
PF (N)	734.1 ± 76.2	779.7 ± 152.8	829.7 ± 101.4	743.1 ± 78.6	7.6 ± 10.9 (ES = 0.46)	13.4 ± 11.5 (ES = 1.22)	1.9 ± 12.9 (ES = 0.11)
RPF ($N \cdot kg^{-1}$)	11.9 ± 1.4	12.6 ± 2.8	13.5 ± 2.5	12.1 ± 1.5	7.8 ± 11.2 (ES = 0.45)	13.1 ± 12.2 (ES = 1.10)	2.6 ± 13.1 (ES = 0.18)
EI ($N \cdot s^{-1}$)	73.5 ± 11.8	73.6 ± 11.2	77.5 ± 11.5	77.7 ± 9.7	5.6 ± 6.4 (ES = 0.03)	6.2 ± 13.3 (ES = 0.47)	6.8 ± 13.3 (ES = 0.53)
CI ($N \cdot s^{-1}$)	139.7 ± 12.5	143.8 ± 14.0	148.7 ± 13.0	145.1 ± 9.7	3.6 ± 5.2 (ES = 0.54)	6.6 ± 6.8 (ES = 1.03)	4.0 ± 7.4 (ES = 0.56)
PP (W)	2511.7 ± 162.9	2637.3 ± 171.0*	2769.4 ± 255.6*	2752.3 ± 238.1*	5.2 ± 5.4 (ES = 1.30)	10.3 ± 8.2 (ES = 1.32)	9.6 ± 6.5 (ES = 1.57)
RPP ($W \cdot kg^{-1}$)	40.6 ± 3.9	42.4 ± 3.7	44.5 ± 5.5*	44.8 ± 4.8	5.0 ± 5.4 (ES = 0.98)	9.6 ± 8.6 (ES = 1.23)	10.4 ± 6.6 (ES = 1.74)
EAP (W)	345.7 ± 91.0	330.1 ± 97.4	370.2 ± 65.3	353.5 ± 55.0	13.6 ± 17.2 (ES = 0.20)	11.4 ± 25.7 (ES = 0.39)	8.3 ± 35.1 (ES = 0.11)
CAP (W)	1308.3 ± 126.2	1378.5 ± 155.2	1462.8 ± 155.8*§	1412.0 ± 132.2	6.6 ± 5.9 (ES = 0.91)	12.0 ± 7.8 (ES = 1.64)	8.3 ± 9.2 (ES = 1.04)
CMJ20							
JH (cm)	16.4 ± 2.1	17.0 ± 2.0	18.5 ± 2.1	18.5 ± 2.7*	5.5 ± 13.1 (ES = 0.61)	14.2 ± 18.0 (ES = 0.81)	13.3 ± 10.7 (ES = 0.85)
RSI ($m \cdot s^{-1}$)	0.18 ± 0.03	0.18 ± 0.04	0.21 ± 0.04	0.19 ± 0.03	12.3 ± 11.0 (ES = 0.13)	14.3 ± 18.4 (ES = 0.85)	8.9 ± 23.3 (ES = 0.34)
PF (N)	684.3 ± 83.3	714.1 ± 132.6	798.2 ± 130.1	702.5 ± 50.4	13.2 ± 17.3(ES = 0.38)	17.3 ± 18.2 (ES = 0.77)	3.8 ± 13.1 (ES = 0.14)
RPF ($N \cdot kg^{-1}$)	8.4 ± 1.1	8.7 ± 1.8	9.8 ± 2.1	8.7 ± 0.9	13.4 ± 17.9 (ES = 0.36)	17.1 ± 18.7 (ES = 0.96)	4.6 ± 13.2 (ES = 0.33)
EI ($N \cdot s^{-1}$)	86.5 ± 11.6	88.9 ± 11.8	89.5 ± 9.9	90.2 ± 9.3	0.9 ± 6.5 (ES = 0.35)	4.1 ± 8.0 (ES = 0.59)	5.6 ± 15.6 (ES = 0.38)
CI ($N \cdot s^{-1}$)	150.3 ± 18.3	157.7 ± 17.4*	160.5 ± 13.1	156.3 ± 14.4	2.4 ± 6.6 (ES = 1.54)	7.5 ± 9.3 (ES = 0.79)	4.3 ± 5.5 (ES = 0.74)
PP (W)	2,483.1 ± 185.9	2,596.7 ± 188.8	2,696.4 ± 232.5	2,667.8 ± 173.4*	4.3 ± 7.5 (ES = 1.14)	8.9 ± 10.4 (ES = 0.92)	7.7 ± 6.2 (ES = 1.37)
RPP ($W \cdot kg^{-1}$)	30.4 ± 2.5	31.7 ± 2.1	32.9 ± 2.9	33.0 ± 2.5*	4.3 ± 8.1 (ES = 0.91)	8.6 ± 11.2 (ES = 0.84)	8.5 ± 6.6 (ES = 1.49)
EAP (W)	463.6 ± 92.2	446.9 ± 118.1	467.5 ± 100.1	441.6 ± 77.6	5.1 ± 14.7 (ES = 0.31)	0.8 ± 8.0 (ES = 0.11)	3.8 ± 11.8 (ES = 0.50)
CAP (W)	1,215.4 ± 153.5	1,275.6 ± 180.5	1,332.8 ± 198.1	1,286.8 ± 124.5	4.9 ± 7.6 (ES = 0.65)	9.9 ± 10.7 (ES = 0.92)	6.6 ± 9.8 (ES = 0.73)

*d_z, Cohen's d_z effect size; NC_1, 1st non-conference match-play; NC_2, 7th non-conference match-play; C_1, 1st conference match-play; C_2, 6th conference match-play; CMJ0, countermovement jump with a polyvinyl chloride pipe; CMJ20, countermovement jump with a 20-kg barbell; BW, body weight; JH, jump height; RSI, modified reactive strength index; PF, peak force; RPF, relative PF; EI, eccentric impulse; CI, concentric impulse; PP, peak power; RPP, relative PP; EAP, eccentric average power; CAP, concentric average power. *denotes $p \leq 0.05$ from NC_1 and §denotes $p \leq 0.05$ from NC_2.*

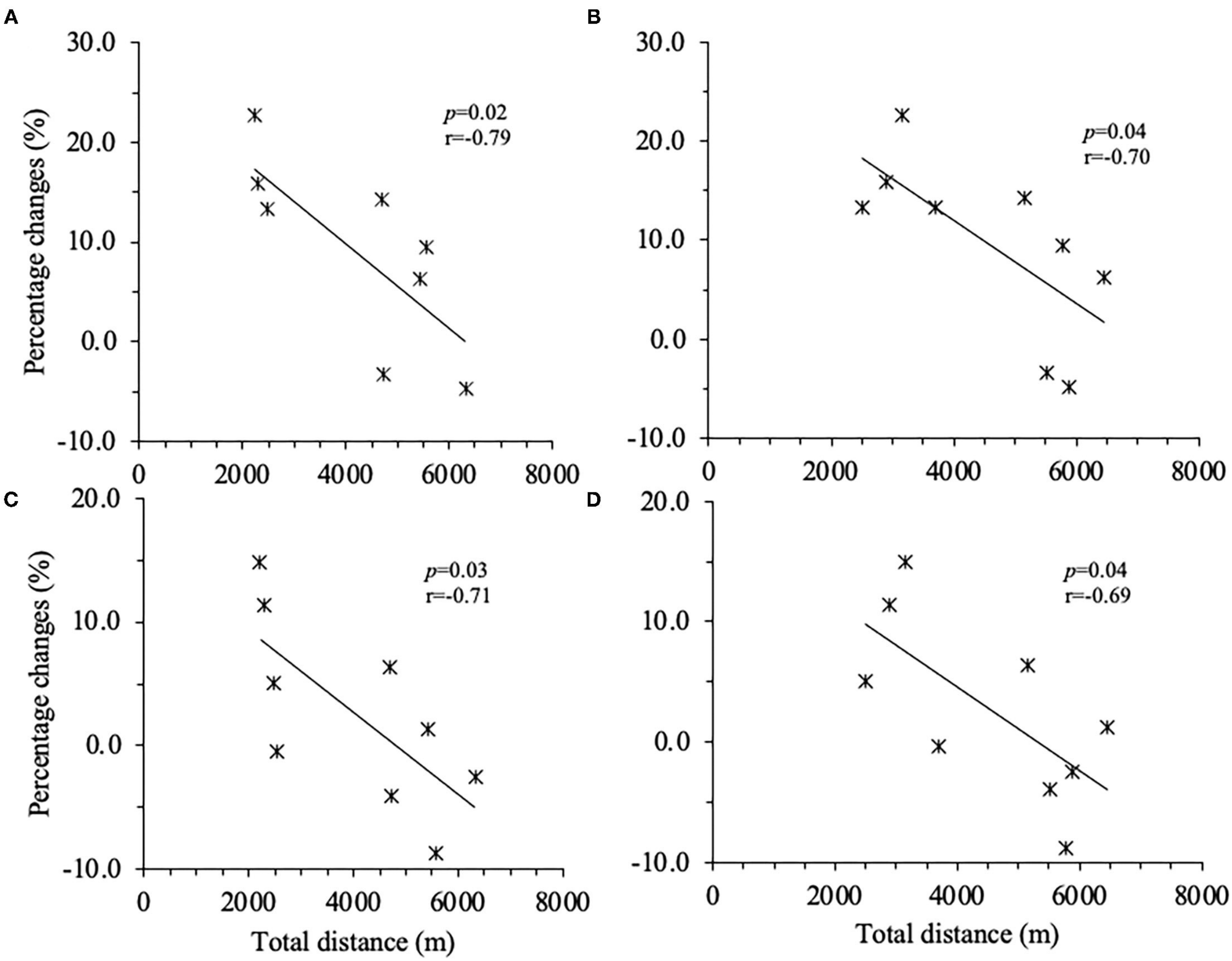

FIGURE 2 | Correlations between percentage changes from 1st non-conference match-play to 6th conference match-play inunloaded countermovement jump (CMJO) jump height and peak power and total distance. **(A)** Between jump height and D_7 total distance, **(B)** between jump height and D_{21} total distance, **(C)** peak power and D_7 total distance, and **(D)** peak power and D_{21} total distance. D_7 = average of 7 days. D_{21} = average of 21 days.

DISCUSSION

The purposes of this study were to investigate: (1) seasonal changes in TL, neuromuscular performance, subjective recovery, and stress state and (2) the relationships between TL and neuromuscular changes in division I collegiate female soccer players. The main findings of this study were: (1) D_7 total distance and PlayerLoad were lower at the conference period than the pre-season and non-conference periods, (2) CMJ0 JH, PP, and RSI were statistically higher at C_1 than NC_1, (3) positive correlations were found between D_7 PlayerLoad and unloaded CMJ JH, PP, and PF at C_1 while negative correlations were observed between D_2 and D_7 total distance and CMJ0 JH and PP at C_2. This study showed that neuromuscular performance gradually increased from the pre-season to the conference play and there was a negative relationship between D_7 TL and CMJ at C_2.

In professional and NCAA soccer, a pre-season is considered as a physical preparatory phase to develop physical capabilities for 2–4 weeks prior to the competitive season. However, practitioners are aware that the length of the pre-season would not be sufficient to adequately improve characteristics of fitness (Dragijsky et al., 2017; Sams et al., 2018; Emmonds et al., 2020; McFadden et al., 2020). The short pre-season may also not provide sufficient recovery time between training sessions, potentially resulting in greater physiological and psychological damage (McFadden et al., 2020; Nobari et al., 2021a,b). Our data indicate that D_7 total distance and PlayerLoad at C_1 were statistically lower than NC_1 and NC_2. This agrees with current evidence that soccer players will typically accumulate higher TLs during the pre-season and the early competitive season (Malone et al., 2015; Clemente et al., 2019, 2020). For example, Malone et al. (2015) found that total distance was substantially higher during the early competitive season (weeks 7–12) compared to the end of the competitive season (weeks 37–42) in elite English male soccer players ($p < 0.05$, ES = 0.84). Therefore, similar to previous investigations (Malone et al., 2015; Clemente et al., 2019, 2020), TL was highest during the pre-season and the early competitive season in the Division I NCAA female soccer players. However, the NCAA female soccer players may not accumulate sufficient TL after the summer break (May–July). Therefore, practitioners may need to manipulate and progress from the pre to the early competitive season to minimize the risk of injuries.

CMJ0 JH, RSI, and PP statistically increased from NC_1 to C_1, although weight training frequency was inconsistent and limited from NC_1 to C_1. Similar to our findings, several studies (Dragijsky et al., 2017; Sams et al., 2018; Emmonds et al., 2020) have shown that neuromuscular performance improves among soccer players from pre-season to the mid or end of the competitive season. Sams et al. (2018) reported that squat JH showed a moderate increase from baseline to the 8th match of the competitive season ($p = 0.039$, ES = 1.01) in the NCAA Division I female soccer players. Improved neuromuscular performance at the mid and end of the competitive season may be explained by the training status of the players prior to the NCAA pre-season. The NCAA prohibits division I soccer teams from starting pre-season until 2–3 weeks prior to the first competition (National Collegiate Athletic National Collegiate Athlete Association, 2021). Nonetheless, the NCAA also restricts strength and conditioning coaches from having mandatory physical training sessions and monitoring their TL during the summer period (12–14 weeks from May to early August). The NCAA restrictions could be detrimental for reasonable TL maintenance or accumulation during the summer and can result in a sudden increase in TL at pre-season, increasing the risk of injuries, muscle damage, and autonomic nervous system fatigue (Agel and Schisel, 2013; Walker et al., 2019; Sekiguchi et al., 2021). The 2–3 weeks of pre-season, as a result of the NCAA regulation, may leave players physically underprepared during the non-conference play and the 12–16 weeks of the competitive season.

The correlations between D_7 TL and CMJ0 changes were positive at C_1, while very large negative correlations were observed between D_7 total distance and CMJ0 JH and PP at C_2. These findings may indicate that the relationship between TL and neuromuscular performance may be altered across the competitive season. Our finding at C_2 agrees with the numerous previous findings (Andersson et al., 2008; Silva et al., 2018; Hader et al., 2019) indicating that jump performance can be negatively affected both acutely and chronically by training. For example, a meta-analysis by Hader et al. (2019) reported that a large negative correlation was found between high-speed running distance (>19.8 km/h) and the CMJ0 PP ($r = 0.52$, 95% CI 0.64–0.40) at 24 h post-match. However, the correlations between D_7 TL and CMJ0 changes were positive at C_1. The disagreement between our finding and previous literature (Andersson et al., 2008; Silva et al., 2018; Hader et al., 2019) may be explained by the training status of the player. The NCAA soccer players may be in physically undertrained status due to the lack of insufficient training volume prior to the pre-season. When prescribing intense/high volume during 2–3 weeks of a pre-season, the training prescription may increase the neuromuscular performance of the player from the pre-season to the mid and late competitive season (Dragijsky et al., 2017; Sams et al., 2018; Emmonds et al., 2020) resulting in the positive correlations between D_7 TL and CMJ0 changes from NC_1 to C_1. Based on our findings and previous literature (Dragijsky et al., 2017; Sams et al., 2018; Emmonds et al., 2020), the effects of seasonal variations may affect the assessment of neuromuscular performance in relation to TL in NCAA soccer.

LIMITATIONS

There are three main limitations of this study. First, the sample size of this study was limited. The data were collected as a part of ongoing athlete monitoring, so this study could not maintain large sample sizes due to injuries affecting jump testing. Second, there were no measures of additional physical performance abilities such as maximum strength, sprinting, change of directions, and intermittent endurance performance over the period. Third, no internal TL measures were included in this study. Future investigation should include other performance tests and examine the effects of weight training sessions with larger sample sizes.

Practical Application

In the NCAA Division I female soccer players, CMJ0 and CMJ20 may increase from the first match play to the midcompetitive and late season. Practitioners (e.g., sports coaches, strength and conditioning coaches, sports scientists) should be aware that longer-term strategic training plans may be required to develop and maximize neuromuscular performance at the end of the competitive season. The practitioners should also carefully impart to collegiate athletes the importance of the quantification of the summer and pre-season TL for maximizing neuromuscular performance at the early competitive season. In addition, care should also be taken when analyzing and interpreting the relationship between acute TL and CMJ0 performance due to the seasonal variations associated with physical preparedness of the player. Our findings demonstrate that CMJs may be a worthwhile test to quantify neuromuscular alternations at the mid and end of the competitive season.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by East Tennessee State University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AI, CB, AS, MS, and JG contributed to study design and implementation. AI and JG carried out all the data collection and analysis. All authors contributed to data analysis, interpretation, discussion of the results, editing and reviewing of the article, and read and agreed to the final version of the submitted manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2021.757253/full#supplementary-material

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REVIEW
published: 29 October 2021
doi: 10.3389/fphys.2021.711634

Quantifying Fatigue in the Rugby Codes: The Interplay Between Collision Characteristics and Neuromuscular Performance, Biochemical Measures, and Self-Reported Assessments of Fatigue

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OPEN ACCESS

Edited by:
Jason Moran,
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Reviewed by:
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Alexandru Nicolae Ungureanu,
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Specialty section:
This article was submitted to
Exercise Physiology,
a section of the journal
Frontiers in Physiology

Received: 18 May 2021
Accepted: 30 September 2021
Published: 29 October 2021

Citation:
Naughton M, McLean S, Scott TJ, Weaving D and Solomon C (2021) Quantifying Fatigue in the Rugby Codes: The Interplay Between Collision Characteristics and Neuromuscular Performance, Biochemical Measures, and Self-Reported Assessments of Fatigue. Front. Physiol. 12:711634. doi: 10.3389/fphys.2021.711634

Locomotor and collision actions that rugby players complete during match-play often lead to substantial fatigue, and in turn, delays in recovery. The methods used to quantify post-match fatigue and recovery can be categorised as subjective and objective, with match-related collision characteristics thought to have a primary role in modulating these recovery measures. The aim of this review was to (1) evaluate how post-match recovery has been quantified in the rugby football codes (i.e., rugby league, rugby union, and rugby sevens), (2) to explore the time-course of commonly used measures of fatigue post-match, and (3) to investigate the relationships between game-related collisions and fatigue metrics. The available evidence suggests that upper-, and lower-body neuromuscular performance are negatively affected, and biomarkers of muscular damage and inflammation increase in the hours and days following match-play, with the largest differences being at 12–36 h post-match. The magnitude of such responses varies within and between neuromuscular performance ($\Delta \leq 36\%$, $n = 13$ studies) and tissue biomarker ($\Delta \leq 585\%$, $n = 18$ studies) measures, but nevertheless appears strongly related to collision frequency and intensity. Likewise, the increase in perceived soreness in the hours and days post-match strongly correlate to collision characteristics across the rugby football codes. Within these findings, there are specific differences in positional groups and recovery trajectories between the codes which relate to athlete characteristics, and/or locomotor and collision characteristics. Finally, based on these findings, we offer a conceptual model of fatigue which details the multidimensional latent structure of the load to fatigue relationship contextualised to rugby. Research to date has been limited to univariate associations to explore relationships between collision characteristics and recovery, and multivariate methods are necessary and recommended to account for the latent structures of match-play external load and post-match fatigue constructs. Practitioners should be aware of the typical time windows of fatigue recovery and utilise both subjective and objective metrics to holistically quantify post-match recovery in rugby.

Keywords: rugby, fatigue, recovery, muscle damage, external load, neuromuscular, biomarker, subjective

INTRODUCTION

Team-based contact sports such as rugby league, rugby union, and rugby sevens are considered stochastic in nature, with players completing periods of low intensity activity (such as walking or jogging) interspersed with high-intensity actions including sprints, change of directions, rapid accelerations and decelerations, and tackles – often defined as the external load (Cunniffe et al., 2009; Coutts et al., 2010; Johnston et al., 2014a, 2018; Till et al., 2020). To adequately prepare for these demands, team sport players are required to have well developed endurance, speed and power capacities (Nédélec et al., 2012); undertaking a variety of training modalities within their programme alongside competitive matches. These varied activities impose complex psycho-physiological and biomechanical training loads onto players, leading to elevated psycho-physiological responses (defined as internal load) that result in increased post-match and post-training fatigue (Daanen et al., 2012; Johnston et al., 2014a; Vanrenterghem et al., 2017; Impellizzeri et al., 2019). Fatigue is a complex construct with a number of context-specific definitions, as well as mechanistic interpretations (i.e., central vs. peripheral) (Enoka and Duchateau, 2016; Jeffries et al., 2021). However, in the context of exposure to an exercise bout (such as rugby match-play), and in the context of this review, fatigue can be considered the disruption of homoeostasis that negatively impacts the ability to produce and apply force (Vøllestad, 1997). Fatigue processes possess acute and chronic dimensions and are therefore time-dependent, although they typically recover toward baseline following the acute effects of match-play (Aben et al., 2020). Muscle damage as a result of match-related activities has the potential to exacerbate fatigue symptoms and delay recovery (Peake et al., 2016). During the competitive season, which comprises weekly matches, prolonged fatigue, and delayed recovery is a challenge for coaches and support staff as they seek to manage, improve, or maintain athlete performance and minimise injuries. It is therefore important for players and practitioners to understand the typical (and therefore atypical) fatigue time-course following match-play, consider the measures (such as performance, physiological markers, etc.) that are currently used to quantify post-match recovery, and understand the influence of match-related actions (such as collisions) which can contribute to delays in recovery.

Athletic recovery is complex and multifaceted and involves the integration and interaction of multiple biological components such as the biochemical, hormonal, biomechanical, morphological, and psychological systems (Daanen et al., 2012; Nédélec et al., 2012). The complex interactions between these (and other) biological systems contribute to the return to homoeostasis acutely post-match due to decreased autonomic sympathetic drive, heart rate, oxygen consumption, and a return to the resting haematological and hormonal states (Daanen et al., 2012). Within skeletal muscle, other transient changes, such as the upregulation of glycogen resynthesis and an increased protein synthesis, are identified post-exercise (Hausswirth and Le Meur, 2011). In the days following exercise, recovery of skeletal muscle is determined by the psycho-physiological and biochemical stress imposed by the exercise bout (Nédélec et al., 2012), and may extend past 72 h post-exercise if the exercise bout characteristics [such as exercise duration and intensity (i.e., load)] are sufficiently high to exceed the athlete's capacity to recovery acutely (Peake et al., 2016). To augment aspects of recovery, players may apply interventions such as hydrotherapies, cryotherapies, compression garments, and nutritional supplements during the post-match or training recovery period. These are outside the scope of this review and have been reviewed elsewhere (Howatson and Van Someren, 2008; King and Duffield, 2009; Hausswirth and Le Meur, 2011).

A fundamental factor which may influence these recovery dynamics is the induction of skeletal muscle damage as a consequence of eccentric or high-intensity exercise, known as exercise-induced muscle damage (EIMD) (Hyldahl and Hubal, 2014; Place et al., 2015; Peake et al., 2016). Rapid or repeated muscle lengthening contractions that occur during activities such as wrestling, plyometric exercise and sprinting can result in EIMD (Hyldahl and Hubal, 2014). These eccentric actions instigate myofibril disruption, which is characterised by a temporary loss of muscle force and power, increased oedema, the transient loss of range of motion, the systemic efflux of muscle bound proteins and enzymes [such as creatine kinase (CK) and myoglobin (Mb)], and delayed onset muscle soreness (DOMS) (Howatson and Van Someren, 2008; Hyldahl and Hubal, 2014; Peake et al., 2016). Following the exercise bout, activated immune and inflammatory cells (e.g., neutrophils, macrophages, and lymphocytes) migrate to the relevant sites to repair and remodel the damaged tissue, leading to a rise in pro- and anti-inflammatory markers such as the Interleukins, and C-reactive protein (CRP) (Hyldahl and Hubal, 2014; Chazaud, 2016). It has been suggested that the initial (24–48 h) loss of function (i.e., strength) that occurs following muscle damage can be ascribed primarily to intracellular calcium efflux and the associated decline in the excitation-contraction coupling pathway (Warren et al., 2002). The remainder of the strength loss that is observed thereafter can be attributed the removal of the force-generating protein structure resulting in a loss of muscle protein content (Warren et al., 2002). Repeated exposure to EIMD leads to adaptations that reduce the associated symptoms compared to prior exposures; a phenomenon known as the "repeated bout effect" (McHugh et al., 1999; Peake et al., 2016). The local and systemic effects of muscle damage and inflammation, and the strategies used to treat EIMD have been extensively reviewed elsewhere (Clarkson and Hubal, 2002; Howatson and Van Someren, 2008; Hyldahl and Hubal, 2014; Chazaud, 2016; Peake et al., 2016).

The collisions that characterise contact sports primarily occur during a tackle event between opposing players [i.e., ball carrier and tackler(s)] and may result in collision- or impact-induced muscle damage (IIMD) (**Figure 1**; Lindsay et al., 2016; Costello et al., 2018; Naughton et al., 2018). This form of muscle damage occurs via compression of skeletal muscle at and/or adjacent to the impact site (Järvinen et al., 2005). Direct muscle trauma is thought to result in tissue necrosis, systemic release of muscle-bound enzymes and proteins (such as CK and Mb), and the influx of pro-inflammatory markers (such as CRP) similar to the development of EIMD (Takarada, 2003; Naughton et al., 2018). Likewise, IIMD is believed to increase intramuscular swelling and to sensitise local nociceptors to induce the sensation of collision-related soreness (Fletcher et al., 2016; Naughton et al., 2018). These processes negatively influence performance through decreased force generation via attenuated excitation-contraction coupling (Naughton et al., 2018), and to drive an increased resting metabolic rate and a shift in tissue substrate utilisation (Costello et al., 2018; Hudson et al., 2019). It is therefore apparent that EIMD and IIMD contribute to the elevated psycho-physiological and biomechanical load imposed through training and competition in contact sports such as rugby league, rugby union, and rugby sevens (hereafter collectively referred to as rugby). Importantly, these factors have been implicated as contributing to delays in post-match recovery within rugby (McLellan et al., 2011b). There are differences in the match demands between the rugby codes. For example, rugby sevens players complete shorter duration matches over multiple-day tournaments where athletes run 1.2–1.4 km per match at an average speed of 113 m min^{-1} (Henderson et al., 2018), compared to rugby union in which athletes complete $\sim$5.0 km per match at velocities of 78–99 m min^{-1} (depending on position) (Tee et al., 2016). Further, rugby sevens is more homogenous for positional groups, compared to the other rugby codes (Ross et al., 2015). Whilst previous work has summarised and examined the post-match fatigue and recovery across the rugby codes, this research did not explore the influence of collision characteristics on recovery measures (Aben et al., 2020). This omission is important, given the purported contribution of collisions to elevated psycho-physiological and biomechanical load outlined above.

Rugby players typically complete repeated rapid change of direction movements, accelerations and decelerations, sprinting, and tackling during match-play (Waldron et al., 2011; Cummins et al., 2013; Oxendale et al., 2016; Till et al., 2020). Further analysis has revealed that the demands of professional match-play vary by competition (Twist et al., 2014), and differ depending on contextual factors such as technical and tactical factors, individual characteristics, and athlete positions (Oxendale et al., 2016; Dalton-Barron et al., 2020; Till et al., 2020). The actions which contribute to external load differ between positional groups. For example, in rugby league the backs positional group (i.e., the fullback, wingers, centres, half-back, and five-eight) complete a greater volume of high-speed running and high-intensity accelerations per match compared to forwards (i.e., the lock, backrowers, props, and hooker) (Cummins et al., 2013; Oxendale et al., 2016). In rugby league and rugby union, forwards complete a higher frequency of total collisions compared to backs, which has been attributed to additional defensive contacts (Twist et al., 2012; Oxendale et al., 2016; MacLeod et al., 2018; Naughton et al., 2020). The match-play differences between positional groups in rugby sevens has been described as being more homogenous (Ross et al., 2015). As described above, such elevated external loads in rugby may result in EIMD and IIMD, which has implications for recovery and may influence post-match fatigue differences between positional groups (**Figure 1**; Oxendale et al., 2016; Naughton et al., 2018). Similar to the recovery dynamics following EIMD being dependent on the exercise bout, temporal recovery following IIMD is related to the frequency and intensity of collisions (McLellan et al., 2011b). Therefore, IIMD could interact with EIMD and psycho-physiological and biochemical fatigue-related alterations (Vanrenterghem et al., 2017; Impellizzeri et al., 2019) to prolong post-match recovery to homoeostasis (i.e., baseline). However, whilst the relative importance of EIMD to post-exercise recovery has been examined extensively (Hyldahl and Hubal, 2014; Chazaud, 2016; Peake et al., 2016), the relevance of collisions and IIMD to post-match fatigue in rugby remains to be elucidated (Naughton et al., 2018).

Given the response-type measures used to assess IIMD and EIMD at times overlap, there is potential to confound their effects on match-related fatigue (Naughton et al., 2018), and this needs be considered when reviewing the literature on collisions. Prior work which has summarised post-match fatigue and recovery from rugby more broadly has failed to examine the relative effects of collision characteristics on recovery metrics (Aben et al., 2020). Therefore, the aim of this review is to characterise the variables that have been utilised to quantify post-match fatigue and recovery, and to specifically review the time-course of fatigue in mens rugby post-match, and the associations between fatigue and rugby match-related collisions (i.e., tackles and ball carries) for the team and in positional groups of forwards and backs. This will be reviewed in three categories; (1) neuromuscular performance measures, (2) biochemical measures, and (3) self-reported measures for mens, adult rugby players from all levels of professionalism. The time-course of post-match fatigue is considered from the acute (0–$\leq$12 h) post-match period through to $\geq$72 h post-match, and the strength of the associations is considered using the recommendations of Hopkins for Pearson's *r* product-moment correlations (Hopkins, 1997).

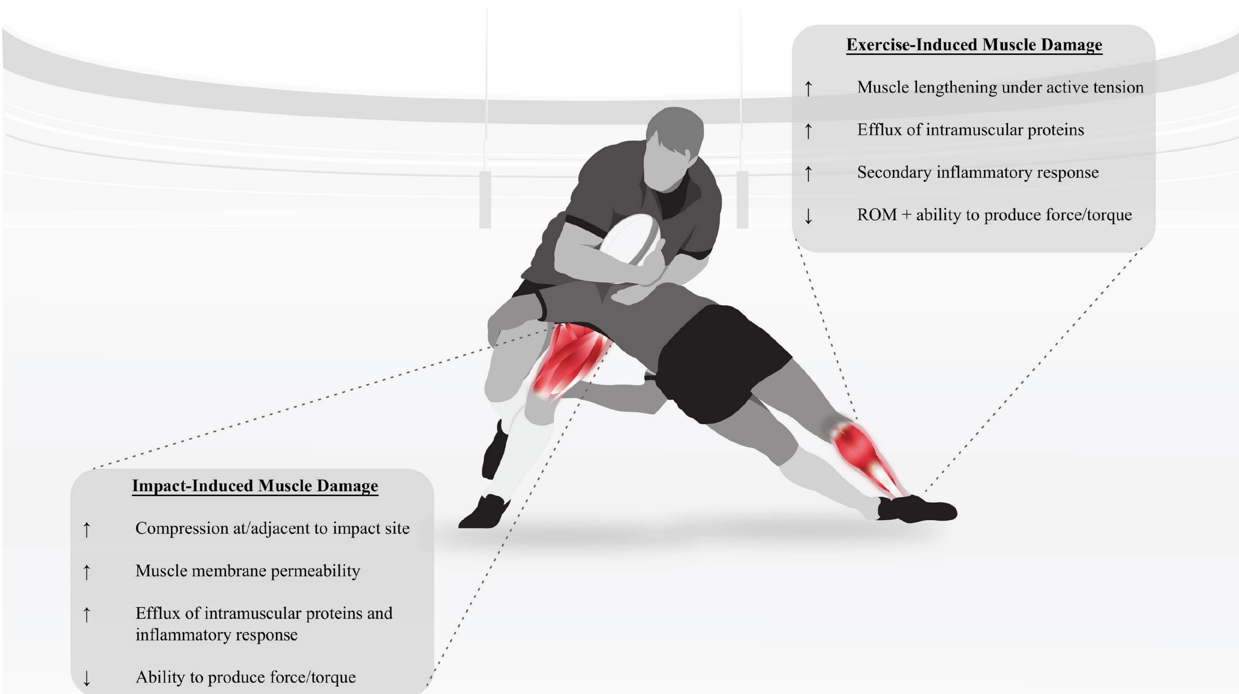

FIGURE 1 | A graphical representation of a rugby collision and its relationship with exercise induced muscle damage (EIMD) (tackler) and impact-induced muscle damage (IIMD) (ball carrier), including the purported effects of EIMD (McHugh et al., 1999; Clarkson and Hubal, 2002; Peake et al., 2005, 2016; Howatson and Van Someren, 2008; Chazaud, 2016), and IIMD (Takarada, 2003; Järvinen et al., 2005; Lindsay et al., 2015b; Naughton et al., 2018). ROM, range of motion.

NEUROMUSCULAR PERFORMANCE

Neuromuscular performance refers to the ability of the neuromuscular system to produce and express force and power (Nuzzo et al., 2019). These variables have been used extensively to provide quantitative measures of fatigue across a range of areas including clinical disease models, overuse injuries, and post-exercise recovery (Nuzzo et al., 2019). Studies in rugby have quantified the post-match neuromuscular performance fatigue time-course using a variety of methods such as countermovement jumps, plyometric push-ups, and knee extension isokinetic dynamometry from the acute (<12 h) post-match period to >72 h post-match (**Table 1**). To further understand the purported effects of collisions on post-match fatigue, the association(s) between match-play collision characteristics (such as frequency and intensity) and the abovementioned post-match fatigue time-course and recovery measures has been investigated.

Countermovement Jump

Time-Course

For countermovement jump analysis, jump height and flight time have been used as measures of neuromuscular performance fatigue (Duffield et al., 2012; Murphy et al., 2013; Skein et al., 2013; Webb et al., 2013; West et al., 2014b; Oxendale et al., 2016). The magnitude of decrease in jump height between studies were variable, with five of the six studies identifying decrements in performance acutely post-match (Duffield et al., 2012; Murphy et al., 2013; Skein et al., 2013; Webb et al., 2013; West et al., 2014b) that extend to 42 h post-match (Webb et al., 2013). Conversely research in amateur players has identified jump height to recover up to 9.7% above baseline at 24 h post-match (Murphy et al., 2013; Skein et al., 2013; **Table 1**). The research on jump flight time appears to be less variable (**Table 1**). Decrements in flight time performance appearing to be largest in the 24–36 h post-match that subsequently recovers 48 h post-match (Oxendale et al., 2016).

Utilising force plates to measure indicators of post-match fatigue and recovery allows insights into how force and power variables fluctuate, and these variables display superior test-retest reliability compared to jump height and flight time (Cormack et al., 2008). Peak force decreased by up to 18.8% (McLellan et al., 2011b; McLellan and Lovell, 2012) in the acute post-match period and returned to above baseline values by 24 h in two studies (McLellan and Lovell, 2012; Johnston et al., 2013; **Table 1**). However, this change was somewhat variable with one study finding peak force remained attenuated to 72 h post-match (McLellan et al., 2011b). Conversely, compared to peak force, larger decrements were identified for peak power throughout the fatigue time-course, with performance decrements of up to 35.8% in the acute post-match period (McLellan et al., 2011b; McLellan and Lovell, 2012; West et al., 2014b; Johnston et al., 2015) which remained diminished to a similar extent at 24–36 h post-match (McLellan et al., 2011b; McLellan and Lovell, 2012; Johnston et al., 2013; West et al., 2014b). Typically, this returned to near baseline levels thereafter (McLellan et al., 2011b; McLellan and Lovell, 2012;

TABLE 1 | Neuromuscular performance changes across post-match recovery.

Study	Rugby code	Measure	Group	Sample (*n*)	Δ to 0–≤12 h (%)	Δ to 12–≤24 h (%)	Δ to 24–≤36 h (%)	Δ to 36–≤48 h (%)	Δ to 48–≤72 h (%)	Δ to ≥72 h (%)
Countermovement jump										
Duffield et al., 2012*#	RL	Height (m)	Team	11	−4.8					
Johnston et al., 2013	RL	PF (N)	Team	7	7.4	2.9	−5.4			
		PP (W)	Team		6.8	−9.4	−9.7			
Johnston et al., 2015	RL	PP (W)	Team	21	−6.5	−3.1		−1.5		
McLellan et al., 2011b	RL	PF (N)	Team	17	−18.8	−8.7		−3.3	3.4	5.0
		PP (W)	Team		−29.5	−21.5		2.5	4.6	14.0
		PRFD ($N{\cdot}s^{-1}$)	Team		−35.8	−27.0		1.1	18.5	17.5
McLellan and Lovell, 2012	RL	PF (N)	Team	22	−16.8	5.5		2.8	14.5	19.0
		PP (W)	Team		−31.5	−36.9		−5.6	6.7	1.8
		PRFD ($N{\cdot}s^{-1}$)	Team		−33.9	−21.8		2.4	7.6	9.1
Murphy et al., 2013*#	RL	Height (m)	Team	9	0.0	9.7				
Oxendale et al., 2016	RL	Flight Time (s)	Team	28	−3.5		−3.6		−2.1	
Shearer et al., 2015	RU	PP (W)	Team	12	−8.0		−5.6		−2.3	
Skein et al., 2013*#	RL	Height (m)	Team	11	−3.1	6.3				
Twist et al., 2012	RL	Flight Time (s)	Forwards	13		−3.3		−1.6		
		Flight Time (s)	Backs	10		−3.0		−3.0		
Webb et al., 2013*	RL	Height (m)	Team	21	−13.8	−14.8		−9.4		
West et al., 2014a$	R7	PP (W)	Team	10		−2.2				
		Height (m)	Team			−6.1				
West et al., 2014b	RU	PP (W)	Team	14	−6.9		−5.7		−2.7	
		Height (m)	Team		−9.0		−5.2		−0.8	
Plyometric pushup										
Johnston et al., 2013	RL	PF (N)	Team	7	2.7	−2.0	−0.6			
		PP (W)	Team		−2.6	−14.9	−21.4			
Johnston et al., 2015	RL	PP (W)	Team	21	−14.6	−10.2		−4.1		
Oxendale et al., 2016	RL	Flight time (s)	Team	28	−4.9		−7.7		−5.8	
Isokinetic dynamometer knee extension										
Duffield et al., 2012*#	RL	MVC ($N{\cdot}m^{-1}$)	Team	11	−7.0					
		PT ($N\ m^{-1}$)	Team		−15.4					
		RTD ($Nm{\cdot}s^{-1}$)	Team		−11.6					
		VA (%)	Team		−0.4					
Murphy et al., 2013*#	RL	MVC ($N{\cdot}m^{-1}$)	Team	9	−11.0	−18.7				
		PT ($N.m^{-1}$)	Team		−33.6	−17.5				
		RTD ($Nm{\cdot}s^{-1}$)	Team		−31.5	−13.4				
		VA (%)	Team		0.1	−4.5				
Skein et al., 2013*#	RL	MVC ($N{\cdot}m^{-1}$)	Team	11	−8.1	−16.2				
		VA (%)	Team		2.0	−4.1				

*All values were converted into percentage change from raw data which was extracted from tables or digitised figures or from percentage change at a given time point reported in each study. *Values are extracted from the control group condition in studies which implemented an intervention in a controlled trial. #Two values were reported in the 0–≤12 h time period, with the earliest value reported post-match extracted for consistency. $Only values reported with respect to day one were included as this was a multi-day rugby sevens tournament. MVC, maximal voluntary contraction; N, Newtons; $Nm{\cdot}s^{-1}$, Newton metres per second; $N{\cdot}m^{-1}$, Newtons per metre; $N{\cdot}s^{-1}$, Newtons per second; PF, peak force; PP, peak power; pRFD, peak rate of force development; PT, peak torque; W, Watts; R7, rugby sevens; RL, rugby league; RTD, rate of torque development; RU, rugby union; VA (%), voluntary activation percentage. Δ - indicates the change from baseline to a given time period.*

West et al., 2014b; Johnston et al., 2015), although one study by Johnston et al. (2013) found a return to above baseline in the acute post-match period. Finally, peak rate of force development was attenuated to a similar extent as peak power in the acute post-match period (35.8%) (McLellan et al., 2011b; McLellan and Lovell, 2012), with performance recovering to 21.8–27.0% below baseline at 24 h post-match, and returning to baseline at 48 h post-match (McLellan et al., 2011b; McLellan and Lovell, 2012).

Associations

For collisions, research in rugby league has investigated the post-match fatigue time-course via the association(s) between match-related collisions dose characteristics (i.e., frequency and intensity), and countermovement jump performance changes at various times in the post-match recovery time-course. For, example, McLellan and Lovell (2012) identified large, significant inverse relationships between total collisions and collisions at higher microtechnology-derived *g* force intensity zones (Naughton et al., 2020) with changes in peak power and peak rate of force development in the acute post-match period (r = –0.60 to –0.73), which remained at 24 h post-match (r = –0.59 to –0.64) (McLellan and Lovell, 2012). Twist et al. (2012) observed similar findings across the team, and further delineated the team into forwards and backs positional groups, and by categorising collisions into offensive and defensive. Significant inverse relationships between total collision frequency and post-match performance attenuation were evident for the forwards, while no such relationship identified for backs (Twist et al., 2012). Similarly, offensive collisions were significantly related to the decrease in post-match performance for forwards, but not for backs. To the author's knowledge, there were no studies that investigated these associations in rugby union or rugby sevens.

Plyometric Push-Up

Time-Course

The generation of upper body force and power is an important factor across rugby (Gabbett and Seibold, 2013). The time-course of upper body fatigue in the post-match period has been quantified through the plyometric push-up test, analysing similar performance metrics to that of the countermovement jump; though limited studies exist and remain exclusively in rugby league (**Table 1**). Oxendale et al. (2016) characterised fatigue using plyometric push-up flight time and observed decrements of up to 7.7% below baseline at 36 h post-match which recovered somewhat to 5.8% below baseline at 60 h post-match.

Analysis of the plyometric push-up through force plates has been utilised in post-match recovery to investigate peak force, and peak power (**Table 1**). In rugby league, Johnston et al. (2013) investigated peak force and observed improvements of 2.7% in performance in the acute post-match period which subsequently declined below baseline performance by 2.0% at 24 h post-match, and then recovered to above baseline levels. However, these fluctuations are within the test-retest coefficient of variation (CV) for peak force (CV = 3.9%) (Parry et al., 2020). The largest differences in plyometric push-up performance have been examined with the peak power metric, with acute decrements up to 14.6% identified immediately post-match, which declined further to 14.9% at 24 h post-match (Johnston et al., 2013, 2015), and 21.4% below baseline at 48 h post-match (Johnston et al., 2013). Finally, a separate study by Johnston et al. (2015) identified peak power to recover to 4.1% below baseline performance at 48 h post-match.

Associations

There is currently one known study to investigate the association(s) between match-related collision characteristics and post-match plyometric push-up flight time performance in post-match recovery. Oxendale et al. (2016) explored this relationship at the team level in professional rugby league players and identified a moderate significant inverse relationship between total match-play collisions and plyometric push-up flight time at 12 h post-match (r = –0.48). The authors further explored the frequency of collisions in various *g* force intensity zones derived from player-worn 10 Hz microtechnology units (MinimaxX, Catapult Innovations, Melbourne, Australia), and identified a significant large association between moderate intensity (3–4.5 g) collisions and change in plyometric push-up performance at 12 h post-match (r = –0.54). All other zone correlations were statistically non-significant ($p > 0.05$).

Isokinetic Dynamometry

Time-Course

The countermovement jump and plyometric push-up are considered dynamic tests for macro-level performance, whereas isokinetic dynamometry can provide insights into intra-muscular and isolated movement fatigue (Gleeson and Mercer, 1996). Isokinetic dynamometers provide varying resistance to allow constant velocity through a joints range of motion (Gleeson and Mercer, 1996). Isokinetic dynamometry has been utilised across three studies in rugby league in which knee extension performance has been assessed isometrically by maximal voluntary contraction (MVC), peak torque and rate of torque development, and electrically evoked twitch characteristics (Duffield et al., 2012; Murphy et al., 2013; Skein et al., 2013; **Table 1**).

Relative to pre-match performance MVC of the knee extensors was reduced by up to 11.0% in the acute ≤12 h post-match period (Duffield et al., 2012; Murphy et al., 2013; Skein et al., 2013). These differences were exacerbated when tested again at 18 h post-match as MVC was decreased by up to 18.7% (Murphy et al., 2013; Skein et al., 2013). Peak torque decreased by up to 33.6% acutely post-match (Duffield et al., 2012; Murphy et al., 2013), then partially recovered to 17.5% below baseline by 18 h post-match (Murphy et al., 2013), though this is data from only one study. Finally, rate of torque development followed a similar trajectory to other isokinetic dynamometry derived variables in being decreased by up to 31.5% acutely post-match (Duffield et al., 2012; Murphy et al., 2013), while one study reported partial recovery to 13.4% below baseline at 18 h post-match (Murphy et al., 2013).

Voluntary activation is a measure of the intrinsic contractile properties of the muscle which can be calculated by the percentage difference between the ability to activate the muscle voluntarily and the activation that is elicited by a supraphysiological electrical stimulus during rest and exercise (Shield and Zhou, 2004). Three studies analysed voluntary activation during knee extension isokinetic dynamometry following rugby league match-play (Duffield et al., 2012; Murphy et al., 2013; Skein et al., 2013) (**Table 1**). In the acute post-match period, changes in voluntary activation were variable and ranged from improvements up to 2.0% to decrements of up to 0.4% when compared to baseline (Duffield et al., 2012; Murphy et al., 2013; Skein et al., 2013). These values are within the test-retest CV (CV = 3.0–4.0%) and therefore may be within the minimal detectable difference (Nuzzo et al., 2019). Following this period, voluntary activation declined by up to 4.5% at 18 h post-match (Murphy et al., 2013; Skein et al., 2013). There were no studies which investigated the force production capabilities or muscle contractile properties beyond this period post-match.

Associations

No studies have investigated the association between post-match isokinetic dynamometry variables and the frequency or intensity of collisions during match-play.

Summary

Across all studies investigating jump variables, the change in jump height was highly variable in post-match recovery, whilst there were more consistent findings for flight time with small decrements identified up to 60 h post-match (**Table 1**). Utilising jump height and flight time has inherent limitations as players may use alternate movement strategies (such as manipulating contraction time) to achieve similar performance (Cormack et al., 2008). Given such limitations, utilising sophisticated methods of kinetic profiling through force plates/platforms has been advocated (Cormack et al., 2008), and explored within rugby league post-match recovery contexts.

Through force plate analysis, the greatest decrements in countermovement jump and plyometric push-up performance were identified 24–36 h post-match, before returning to baseline within 48–72 h (**Table 1**). Both peak power and peak rate of force development appear to be attenuated to a greater degree than peak force, height, and flight time in post-match recovery. This observation has been noted by others (Twist et al., 2012; Johnston et al., 2013; Twist and Highton, 2013). From these findings it appears that metrics that incorporate a velocity component (such as peak power and peak rate of force development) are more sensitive to post-match fatigue than metrics that do not. Whilst the mechanism(s) of this are still not known, this has been proposed to involve preferential damage to Type II skeletal muscle fibres stimulating a shift in the force-velocity relationship to slower movement velocities which does not affect peak force generation capacity to the same extent (Johnston et al., 2013).

Isokinetic dynamometry performance decrements suggest that alterations in the properties of isolated lower-limb movements following match-play align directionally with the macro-level performance changes identified during dynamic tests, such as the countermovement jump (Murphy et al., 2013; Skein et al., 2013). However, there are financial and logistical constraints to isokinetic dynamometry as equipment is costly and bulky making it difficult to transport and setup (Gleeson and Mercer, 1996). These limitations make it impractical for practitioners to use and test large groups of players outside of research settings. Within research settings, these factors have likely contributed to the lack of studies that investigate isokinetic performance beyond the 12 h post-match period, and outside of rugby league. Given these considerations, using force plates (when available) to monitor upper-body and lower-body neuromuscular performance fatigue may be a cost and space effective alternative.

The collective findings suggest that the frequency and intensity of match-related collisions are related to the attenuation in performance post-match. Further, the observations of Twist et al. (2012) highlight a potential differential fatigue mechanism between positional groups as to the specific match-related actions that produce divergent fatigue responses (Fletcher et al., 2016). For forwards, the higher frequency and intensity of match-related collisions compared to backs could translate to a greater degree of IIMD and associated fatigue (Naughton et al., 2018). However, for backs, the decrements in lower-limb performance appear to relate to the greater frequency of high-intensity accelerations and volume of high-speed running (Oxendale et al., 2016).

BIOCHEMICAL MEASURES

To provide objective information about the physiological changes in response to match-play, a variety of biochemical markers have been utilised that relate to muscle damage and inflammation (Cunniffe et al., 2010; Peake et al., 2016). CK and Mb are enzymes expressed in a variety of body tissues that are involved in cellular energetics (Wallimann et al., 1992). The increased presence of the skeletal muscle-bound isoform of CK or Mb in systemic circulation is used quantitatively as a marker of muscle membrane permeability and damage (Peake et al., 2016). Following damage, a secondary inflammatory response is initiated and the systemic concentration of the pro-inflammatory CRP increases to promote breakdown and removal of cellular debris through phagocytosis (Chazaud, 2016). There are several limitations to the application of these methods which have been highlighted in the wider literature, such as the infeasibility of collecting bodily tissues with more professional athlete populations, and the large inter- and intra-individual variability that is often observed at baseline (CK inter-individual CV: 18.5–27.0%; intra-individual CV: 41.7%) and in response to sporting match-play (CK inter-individual CV: 28.1%; intra-individual CV: 30.0–34.3%) (Twist and Highton, 2013; Russell et al., 2015; Harper et al., 2016; Kellmann et al., 2018). Within rugby literature, CK and Mb are the primary markers of muscle damage that have been investigated, while CRP has been utilised as an inflammatory biomarker (**Table 2**). In addition, other biomarkers of neuroendocrine function such as cortisol and testosterone have been investigated with respect to their relevance to post-match fatigue and recovery (Cunniffe et al., 2010; Minett et al., 2010; McLellan et al., 2011a; Murphy et al., 2013; Lindsay et al., 2015a,b; Shearer et al., 2015). Muscle damage and inflammatory processes are known to increase oxidative stress which has been observed in rugby athletes throughout the competitive season (Finaud et al., 2006). However, there is a lack of research which has explored oxidative stress markers acutely prior to and following rugby match-play, which precluded the inclusion of oxidative stress markers in this review.

Creatine Kinase

Time-Course

There were 16 studies that investigated the role of CK in post-match recovery (**Table 2**). Across all players, CK increased relative to baseline by up to 265.5% acutely post-match (Takarada, 2003; Oxendale et al., 2016), which remained elevated (585.0%) in the 12–36 h post-match (**Table 2**) (Takarada, 2003; Skein et al., 2013). Following this peak, there were increases of up to 176.6% relative to baseline in CK evident at 72 h post-match (**Table 2**) (Takarada, 2003; McLellan et al., 2011a). For positional groups,

TABLE 2 | Blood biomarkers of muscle damage and inflammation and their change across post-match recovery.

Study	Rugby code	Group	Sample (*n*)	Δ to 0–≤12 h (%)	Δ to 12–≤24 h (%)	Δ to 24–≤36 h (%)	Δ to 36–≤48 h (%)	Δ to 48–≤72 h (%)	Δ to ≥72 h (%)
Creatine kinase (U/L or IU.L^{-1})									
Cunniffe et al., 2010	RU	Team	10	55.9	255.0		125.2		
da Silva et al., 2020	RU	Team	14	44.9	225.8		74.1	6.3	–21.0
Gill et al., 2006*	RU	Team	23	114.5					
Johnston et al., 2013	RL	Team	7	82.5	175.5	143.8			
Johnston et al., 2015	RL	Team	21		126.0		55.0		
Jones et al., 2014	RU	Backs	13		451.5		197.1		
		Forwards	15		191.6		104.1		
McLellan et al., 2011a	RL	Team	17	50.3	211.6		96.0	83.1	46.4
Minett et al., 2010*	RU	Team	12		133.7				
Murphy et al., 2013*#	RL	Team	9	95.3	162.1				
Oxendale et al., 2016	RL	Team	28	263.3		170.2		19.6	
Suzuki et al., 2004	RU	Team	15	18.0	53.7		–14.2		
Takarada, 2003	RU	Team	15	265.5	585.2		390.5	176.6	
Twist et al., 2012	RL	Backs	10		167.9		88.9		
		Forwards	13		285.1		144.6		
Webb et al., 2013*	RL	Team	21	36.6	167.1		91.5		
West et al., 2014a$	R7	Team	10	152.8	222.2				
Skein et al., 2013*#	RL	Team	11	100.0	225.0				
Myoglobin (μg/L or ng.mL^{-1})									
Lindsay et al., 2015a*¤	RU	Team	18	2589.0		–58.9			
Lindsay et al., 2015b	RU	Team	11	148.5	1.3	–24.7		–38.0	
Takarada, 2003	RU	Team	15	2091.8	191.7		33.3	8.3	
C-reactive Protein (U/L or mg.L^{-1})									
Cunniffe et al., 2010	RU	Team	10	–2.1	121.6		201.0		
Minett et al., 2010*	RU	Team	12		40.0				
Murphy et al., 2013*#	RL	Team	9	9.8	64.1				
Skein et al., 2013*#	RL	Team	11	7.3	46.0				

*All values were converted into percentage change from raw data which was extracted from tables or digitised figures or from percentage change at a given time point reported in each study. *Values are extracted from the control group condition in these studies which implemented an intervention in a controlled trial. #Two values were reported in the 0–≤12 h time period, with the earliest value reported post-match extracted for consistency. $Only values reported with respect to day one were included as this was a multi-day rugby sevens tournament. ¤Raw data was provided by the author on request. IU.L, international equivalent units per litre; mg.L, milligrammes per litre; R7, rugby sevens; RL, rugby league; RU, rugby union. Δ - indicates the change from baseline to a given time period.*

the increases in CK were larger in rugby league for forwards compared to backs at 24 h post-match (285.1 vs. 167.9%), and 48 h post-match (144.6 vs. 88.9%) (Twist et al., 2012). These differences were reversed in rugby union, as backs compared to forwards displayed the largest difference at 24 h post-match (451.5 vs. 191.6%) and 48 h post-match (197.1 vs. 104.1%) (Jones et al., 2014). These changes far exceed the typical test-retest variability highlighted above and can therefore be used to infer tissue damage.

Associations

At the team level, there were significant large to near perfect correlations between match-related total collision frequency and the rise in CK in the acute post-match period (r = 0.67), and at 24 h post-match (r = 0.50–0.92) (Takarada, 2003; Twist et al., 2012; Oxendale et al., 2016). In rugby league, similarly large relationships were identified at 24 h post-match when collisions were divided into offensive and defensive collision frequency (McLellan et al., 2011a; Twist et al., 2012). However, in rugby union, only offensive tackles were significantly correlated to the change in CK at 24 h post-match (Jones et al., 2014). Twist et al. (2012) explored rugby league forward and back positional groups and associations with match-related collision frequency. Significant very large associations were identified between offensive, defensive, and total collisions with the rise in CK at 24 h post-match for forwards (r = 0.70–0.74). Conversely, all relationships for the backs positional groups were statistically non-significant ($p > 0.05$) and had small to trivial effect sizes. In rugby union, the strongest relationships between the change in CK and collisions were seen in the acute post-match period for backs with hit-ups (r = 0.74), and impacts (r = 0.71) (Smart et al., 2008), and at 48 h post-match were for backs with tackles (r = 0.58), and impacts (r = 0.64) (Jones et al., 2014). Compared to backs, relationships for forwards between CK and these collision metrics were smaller and non-significant at these time points.

Relating microtechnology-derived collision intensity metrics to CK changes to quantify post-match fatigue and recovery has also been explored in rugby league (McLellan et al., 2011a; Oxendale et al., 2016). Oxendale et al. (2016) used a five level g force-derived intensity schema from light to severe, and found significant large to very large relationships between the rise of CK in the acute ≤12 h post-match recovery period and microtechnology derived collision intensities equating to zone 1 (2–3 *g*) through to zone 4 (6–8 *g*) (r = 0.58–0.73). McLellan et al. (2011a) utilised a six zone schema and identified significant, large to very large correlations between the increase in CK and collisions in zone 4 (7.1–8.0 *g*) to zone 6 (>10.1 *g*) immediately post-match (r = 0.61–0.63), and 24 h post-match (r = 0.63–0.77). Similarly, statistically significant large correlations between CK and collisions in zone 5 (8.1–10 *g*) and zone 6 (10.1 *g*) were identified at 48 and 72 h post-match, respectively (r = 0.55–0.63). There were no studies to explore these relationships in rugby union or rugby sevens.

Myoglobin

Time-Course

Three studies have investigated the between-individual changes in Mb concentrations from pre-match to post match, exclusively in rugby union (**Table 2**; Takarada, 2003; Lindsay et al., 2015a,b). On a group level, the largest changes in Mb were identified acutely post-match with increases of up to 2589.0% identified during this period (Lindsay et al., 2015a,b, 2016). Thereafter Mb concentrations began to decline but remained elevated above baseline in one study by up to 191.7% and 33.3% at 24 h and 48 h post-match, respectively (Takarada, 2003). However, in two studies Mb concentrations declined below the pre-match baseline by 24–36 h post-match (Lindsay et al., 2015a,b).

Associations

Takarada (2003) is the only study to investigate the relationships between collision characteristics and Mb change post-match in rugby union. A significant, very large correlation (r = 0.85) was identified between tackles completed during match-play and the peak Mb concentration which occurred at 45 min post-match. There are no known studies to investigate Mb associations past this time point, or in rugby league, or rugby sevens.

C-Reactive Protein

Time-Course

Two studies in rugby league and two studies in rugby union have used changes in CRP as a marker of inflammation in response to match-play (Cunniffe et al., 2010; Minett et al., 2010; Murphy et al., 2013; Skein et al., 2013). In rugby league, immediately following match-play, increases of up to 9.8% in CRP were present compared to baseline levels (Murphy et al., 2013; Skein et al., 2013), whilst a decrease in CRP was observed in one study investigating rugby union (Minett et al., 2010). Following this period across both rugby union and rugby league, CRP increased up to 64.1% and 121.6% above baseline concentrations at 16 h and 24 h post-match, respectively (Cunniffe et al., 2010; Minett et al., 2010; Murphy et al., 2013; Skein et al., 2013). In rugby union, the peak change in CRP (201.0%) occurred at 48 h post-match (Cunniffe et al., 2010; **Table 2**).

Associations

There are no studies which investigate the association(s) between CRP concentration and match-related collision characteristics such as frequency or intensity.

Neuroendocrine Markers

Cortisol is a glucocorticoid produced by the kidney that is measured as a systematic psychophysiological stress marker (Salvador and Costa, 2009). As a stress-related hormone, cortisol acts to modulate the stress response to real and perceived stimuli, and is believed to be involved in muscle catabolism, psychological readiness prior to exercise, and aspects of threat perception, anxiety, and mood (Woolf, 1992; Salvador and Costa, 2009; Casto and Edwards, 2016). Testosterone is an endogenous steroid that is involved with anabolic processes such as protein signalling, as well as contributing to muscle glycogen synthesis (Kelly and Jones, 2013). While cortisol and testosterone are negatively correlated at times of competition, describing the purported effects between these neuroendocrine markers as inverse is imprecise as both markers have interrelated physiological effects on a variety of bodily tissues (including following exercise) outside of those described here (Casto and Edwards, 2016).

Time-Course and Associations

Studies have investigated both serum and salivary cortisol immediately following match-play with transient increases of up to 298.0% identified (Cunniffe et al., 2010; McLellan et al., 2010, 2011a; Minett et al., 2010; Murphy et al., 2013; Lindsay et al., 2015a,b; Shearer et al., 2015). Following this time, cortisol decreased to near baseline levels by 24 h post-match (McLellan et al., 2011a; Murphy et al., 2013) and remained at or below pre-match levels until 72 h post-match in all except one study (Cunniffe et al., 2010; McLellan et al., 2010, 2011a; Minett et al., 2010; Lindsay et al., 2015a,b). That study by Shearer et al. (2015) identified consistently increased cortisol of 30.0–52.5% immediately post-match through to 72 h post-match. Finally, McLellan et al. (2011a) investigated the associations between match-related collision frequency and microtechnology-derived (SPI-Pro, GPSports, Canberra, Australia) *g* force intensity zones with post-match cortisol and found no significant relationships at any time point.

For testosterone, increases of 13.0% relative to pre-match baseline were identified immediately post-match in rugby league which continued to rise to 67.0% above baseline at 72 h post-match (McLellan et al., 2010). During this time, these values returned to at or above 24 h pre-match concentrations, and reflected the depression of testosterone that occurred immediately prior to match-play relative to the players typical (i.e., 24 h pre-match) testosterone levels. In rugby union testosterone decreased by up to 43.9% relative to baseline in the acute post-match period (Cunniffe et al., 2010; Shearer et al., 2015) and remained attenuated by 17.9% at 24 h post-match, but recovered to near baseline concentrations thereafter (Cunniffe et al., 2010; Shearer et al., 2015). No studies have investigated changes in testosterone and the frequency or intensity of match-related collisions.

Summary

The large increases in CK and Mb identified immediately post-match continued to remain elevated up to 36 h post-match before decreasing toward baseline. During this time, significant strong relationships between CK and collision frequency and intensity were identified. Taken together, these findings provide further indirect evidence that muscle tissue damage occurs during match-play that relates to collision characteristics (i.e., frequency and intensity) (Naughton et al., 2018). Moreover, in rugby league the forwards positional group have the highest frequency and intensity of collisions and have the higher rates of IIMD and associated post-match increases in CK, as well as decreased upper-, and lower-body performance (Naughton et al., 2020). Positional group evidence in rugby union does not support these findings, with backs exhibiting higher CK concentrations post-match, and stronger relationships with collision characteristics when compared to forwards. It is unclear why these differences exist, but they likely relate to differences in collision characteristics (e.g., contested scrums, rucks, mauls in rugby union and rugby sevens) or locomotor external loads between the rugby codes (Cummins et al., 2013; MacLeod et al., 2018). Further replication work is necessary to confirm or refute these findings.

Observations of elevated CK and Mb in the acute (<12 h) and 24 h post-match recovery periods are supported by subsequent increases in CRP, a secondary inflammatory marker which was increased when sampled at 48 h post-match. This suggests that the delayed inflammatory response following match-play follows the typical biphasic model whereby initial muscle damage and trauma signals the subsequent phase shift and escalation in inflammation (Clarkson and Hubal, 2002). In soccer, a sport without the collision component of rugby, the peak in post-match CRP occurs 24–48 h post-match before returning to baseline by 72 h (Nédélec et al., 2012; Silva et al., 2013). The largest increase in CRP were observed 48 h post-match in rugby union (Cunniffe et al., 2010), and there were no measurements at subsequent times. Moreover, Singh et al. (2011) postulate that CRP is more sensitive to muscle damage recovery involving collisions than markers such as CK and Mb. Whilst the post-match muscle damage marker time-course has been established, exploring CRP beyond 48 h post-match appears necessary to identify the peak and subsequent nadir to further characterise the time-course of post-match inflammation. This is important to establish given the repeated training and matches an athlete is exposed to, such as during the week to week in-season period.

The changes in post-match cortisol and testosterone levels, from the limited research conducted in rugby, indicate that match-play may be associated with heightened arousal, anxiety, and vigilance inducing a cortisol response (Cunniffe et al., 2010; McLellan et al., 2011a). Amongst the myriad of effects, the acute rise in cortisol post-exercise acts to signal the rise in inflammatory mediators (Peake et al., 2005), while systemic changes in testosterone act in skeletal muscle anabolism (McLellan et al., 2010; Kelly and Jones, 2013). However, the time-course of these changes suggests that cortisol increases are typically attenuated by 24 h following the stressor of match-play. Further, for both cortisol and testosterone, the return to baseline remains stable into the subsequent training week, ∼48 h post-match (McLellan et al., 2010, 2011a), a time-course which is consistent with changes across American Football (Kraemer et al., 2009). Overall, these hormonal changes suggest that training is not perceived in the same manner as match-play. A potential explanation for this difference in perception is that there are inherent differences in external load content, such as locomotion and collision characteristics, between match-play and training. Given the limited evidence linking collisions and hormonal changes, as well as the typical recovery of hormonal markers following match-play, the relevance of attempting to monitor or influence the typical fluctuations in cortisol and testosterone post-match would be limited outside of clinical conditions.

SELF-REPORTED ASSESSMENTS

Whilst neuromuscular performance and biochemical measures have been used pre- and post-match to provide objective metrics of fatigue, other questionnaire-based methods have been used to provide subjective assessments of athlete health and well-being (Saw et al., 2016). Within team sport research, there are a number of long-form questionnaires and shorter rating scales which provide insight into a players subjective well-being and psychological readiness state (Saw et al., 2016). Rugby league studies have focussed on assessing soreness using shorter Likert-based scales with numerous scales (such as 0–6, 1–5, or 1–10) to quantify the time course of whole-body, upper-body, and lower-body soreness changes (Twist et al., 2012; Murphy et al., 2013; Skein et al., 2013; Webb et al., 2013; Fletcher et al., 2016; Oxendale et al., 2016). Further, studies in rugby league have explored associations between match-related collision characteristics and soreness at various time-points during post-match recovery (Twist et al., 2012; Fletcher et al., 2016; Oxendale et al., 2016).

Soreness

Time-Course

Increases in perceived total body soreness (as assessed using single-question Likert ratings and visual analogue scales) were observed from pre- to immediately post-match when averaged within the team (Murphy et al., 2013; Skein et al., 2013; Webb et al., 2013; Oxendale et al., 2016). Within the team, soreness increases peaked between 12 and 36 h post-match (Minett et al., 2010; Murphy et al., 2013; Skein et al., 2013; Webb et al., 2013; Oxendale et al., 2016; Kupusarevic et al., 2019), before returning to baseline at 60 h post-match (Oxendale et al., 2016). One study by Twist et al. (2012) in rugby league determined positional differences in post-match whole body soreness using a 5-point Likert scale, and there were similar changes between backs and forwards at 24 h (3.5 vs. 3.2 AU) and 48 h (3.2 vs. 3.3 AU) post-match (Twist et al., 2012).

Fletcher et al. (2016) examined post-match perceived soreness longitudinally throughout a 26 match competitive season. Upper- and lower-body soreness in the backs, forwards, and adjustables positional groups were compared pre-match, and at 24, 48, 72, and 96 h post-match using a 5-point Likert scale, and there were no significant differences between upper-body and lower-body perceived soreness in the positional groups at any post-match time point.

Associations

Two studies in rugby league have examined the associations between collision frequency and soreness changes within the team and across positional groups (Twist et al., 2012; Fletcher et al., 2016). There were significant large correlations between match-related collision frequency and the increase in total body soreness at 24 h post-match in the forwards (r = 0.62), which were absent in the backs and across the whole team (r = 0.20–0.39) (Twist et al., 2012). These position-specific associations were mirrored when collisions were separated into offensive and defensive categories for forwards (r = 0.49–0.63) (Twist et al., 2012). At the same time point (i.e., 24 h post-match), there were significant correlations between total, defensive, and offensive collisions and upper-, and lower-body soreness for forwards and the team (Fletcher et al., 2016). In this research, the strongest relationships were identified for forwards and between defensive collisions and upper-body soreness (r = 0.42). Further significant associations between total collisions and upper- and lower-body-soreness were identified for forwards and across the team at 48 h post-match (Fletcher et al., 2016). For backs, there were no significant associations between offensive or defensive collisions and upper-body or lower-body soreness at any time point in the post-match period (Fletcher et al., 2016).

For collision intensity, a study by Oxendale et al. (2016) in rugby league explored the associations between microtechnology-derived g force collision intensity and soreness in the acute (<12 h) post-match period. Here, collisions in four of the five intensity zones were significantly related to total body soreness changes immediately post-match within the team ($r \geq 0.56$). Further, the total frequency of match collisions across the team were significantly and largely related to total body soreness during the same period (r = 0.68) (Oxendale et al., 2016). There were no studies investigating associations with collision intensity metrics beyond this time point. The associations indicated in this section are from studies in rugby league, with there being no known studies investigating these relationships in rugby union, or rugby sevens.

Summary

The time-course of subjective soreness changes post-match follows a similar trajectory to that of objective markers of neuromuscular performance and blood biomarkers, with the largest differences consistently observed in the 12–36 h post-match period. Similar to the objective methods (discussed above), there were strong relationships for match-related collisions and the rise in soreness in the hours and days following match-play. These associations were particularly pronounced for the forwards positional group and for upper-body soreness with defensive collisions, of which forwards complete a higher frequency per match than backs (Naughton et al., 2020). This supports the hypotheses that IIMD is a primary cause of the delays in recovery following match-play, and a potential divergent fatigue response exists for IIMD and EIMD that may be position-specific (Naughton et al., 2018).

As monitoring tools, subjective methods of data collection likely provide different but complementary information to objective markers in profiling post-match fatigue

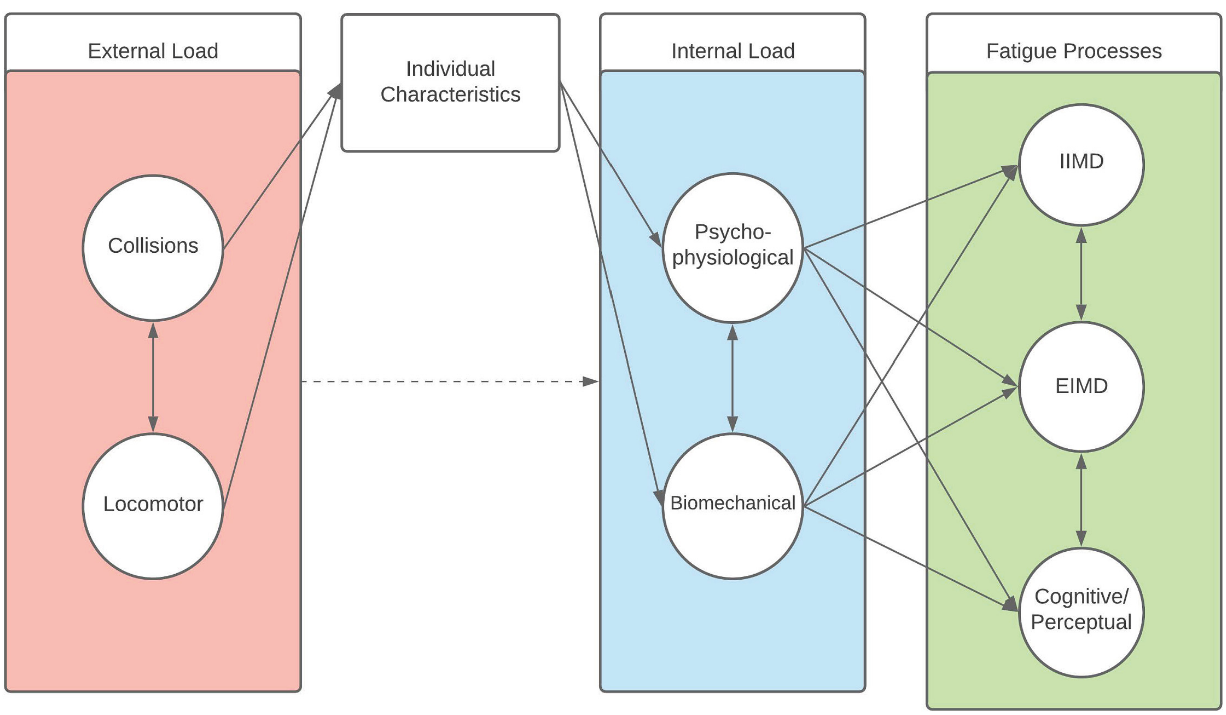

FIGURE 2 | A latent structural equation model *conceptualisation* of the relationship between external load factors, individual characteristics, internal load, and fatigue generating processes [including impact-induced muscle damage (IIMD), and exercise-induced muscle damage (EIMD)] in rugby. Circles represent a construct, rectangles represent an indicator of a construct, single arrows indicate a causal relationship, double-headed arrows represent a bi-directional relationship (e.g., covariance/correlation), and the dashed arrow represents an effect which may be mediated.

(Saw et al., 2016). Therefore, multivariate monitoring of both subjective and objective metrics is relevant when considering the players fatigue and readiness state from a holistic perspective (Colby et al., 2017). For example, an athlete may perform within their typical range (incorporating a measure of variability such as CV or through a Z-score) for a neuromuscular performance test on a given post-match recovery day, whilst their concurrent subjective soreness and wellness data may fall negatively outside their typical range (including variability), or *vice versa* (Robertson et al., 2017; Kellmann et al., 2018). Based on how an athlete scores relative to their typical response, this mismatch would then activate a notification and subsequent discussion between the athlete and supporting practitioners (Robertson et al., 2017), and additional recovery strategies or alterations in training could be implemented. Further, given the low-cost and accessible process of subjective assessment, this information can be readily collected by practitioners and particularly those who do not have access to sophisticated methods such as force platforms, isokinetic dynamometers, or blood collection. Despite their popularity, recent work has identified that a number of these single-item athlete self-report measures lack established validity and are without known measurement properties (Jeffries et al., 2020). Practitioners should therefore be mindful of the validity of the measures and scales when selecting which self-reported measurement techniques to employ.

CONCEPTUAL MODEL OF FATIGUE

This review highlights the multidimensional and complex nature of the load to fatigue paradigm in rugby. Indeed, it is apparent that post-match fatigue (as an outcome) is the consequence of the interplay between external load characteristics, internal load characteristics, and their effects on the fatigue generating processes. Based on the nature of the external loads undertaken during rugby match-play, the influence of external load on the internal load an athlete experiences, and the acute negative post-match fatigue response, these processes can be conceptualised as a model with an inherent multidimensional latent structure. Structural models are path-based methods commonly used to visualise and describe the relationships between unobserved constructs (i.e., latent variables) and observed variables within a given model. We propose that the latent structure (including both match-play content and post-match fatigue) may be appropriately described in a path diagram model from structural equation modelling (**Figure 2**) (Ullman and Bentler, 2003).

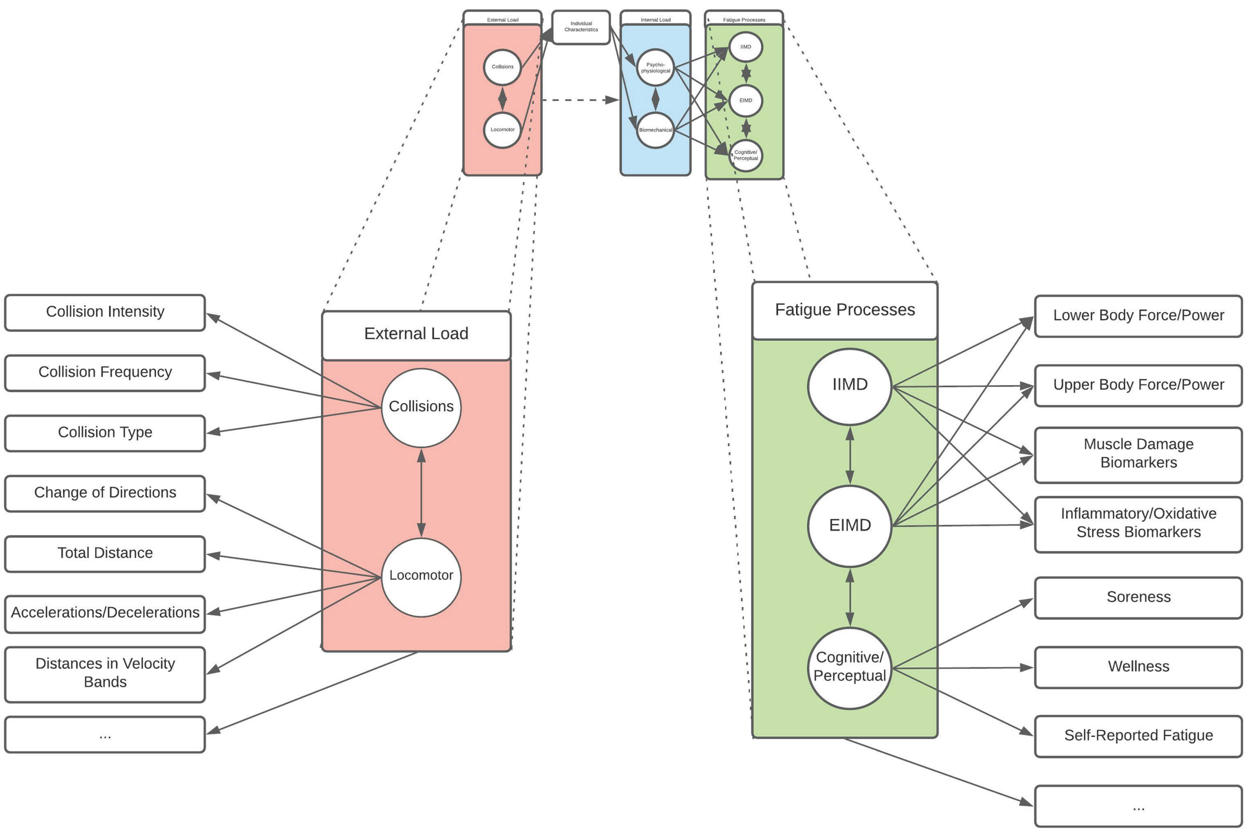

FIGURE 3 | An expanded version of the conceptual model presented in **Figure 2** which includes examples of functional measures of external load variables and fatigue processes such as those explored in this review. Circles represent a construct, rectangles represent an indicator of a construct, single arrows indicate an assumed causal relationship, and double-headed arrows represent a bidirectional relationship (e.g., covariance/correlation). As this model is not intended to be exhaustive, ellipses represent other functional measures which may contribute to external load and fatigue processes, but which are not included in the model.

Here, circles represent the latent constructs, square boxes represent the indicators (i.e., functional measure) of that construct, and arrows align directionally the factors with the relevant constructs (assuming a causal relationship), while double headed arrows indicate an interrelationship between constructs (**Figures 2**, **3**). As demonstrated, collision and locomotor external loads influence the physiological and biomechanical components of internal load that is mediated through the prism of individual characteristics. Consequently, fatigue is experienced by the individual/athlete, modelled as the influence of external and internal loads on the fatigue generating processes of EIMD, IIMD, and cognitive/perceptual fatigue (**Figure 2**). Within each of these latent components (i.e., the circles), there are functional measures and indicators that can be used by practitioners to quantify aspects of the given component (**Figure 3**). This provides a multidimensional, latent structure to the proposed model. For example, collision external loads can be quantified using collision frequency and intensity metrics, whilst locomotor variables can be quantified via high-speed distance, accelerations, decelerations, and total distance metrics (**Figure 3**). Likewise, there are a number of functional measures which can be used to quantify aspects of fatigue (**Figure 3**). This model is a conceptual representation, and the list of factors and constructs, whilst being drawn from the available research, is not intended to be exhaustive. Likewise, it is not intended to be a strict mathematical interpretation of a structural equation model but rather, a conceptual framework illustrating the latent structure inherent to rugby match-play and fatigue. Whilst a variety of indicators exist, it is important that the reliability and validity of such measures is considered when selecting variables to represent an aspect of a given construct.

Given the content of this structure, the model (**Figures 2**, **3**) is considered an application of the revised training process model of Jeffries et al. (2021). In their revised conceptual framework, Jeffries et al. (2021) describes the training effects to either be acute or chronic, and positive or negative based on the temporal nature and the overall effect on sports performance outcomes, respectively. Our model offers a specific application of this framework to rugby match-play which, given the findings of this review, should be considered a specific "acute-negative" illustrative example using the terminology described within their framework. As Jeffries et al. (2021) is a refinement of the internal/external training load models of Impellizzeri et al. (2005, 2019), it incorporates elements of this prior conceptual work alongside other models, including the seminal Bannister fitness-fatigue model (Morton et al., 1990). Further, our model aligns with that of Vanrenterghem et al. (2017) by conceptualising internal load as incorporating both physiological and biomechanical components (and subcomponents), and the work of Enoka and Duchateau (2016) by integrating perceptual

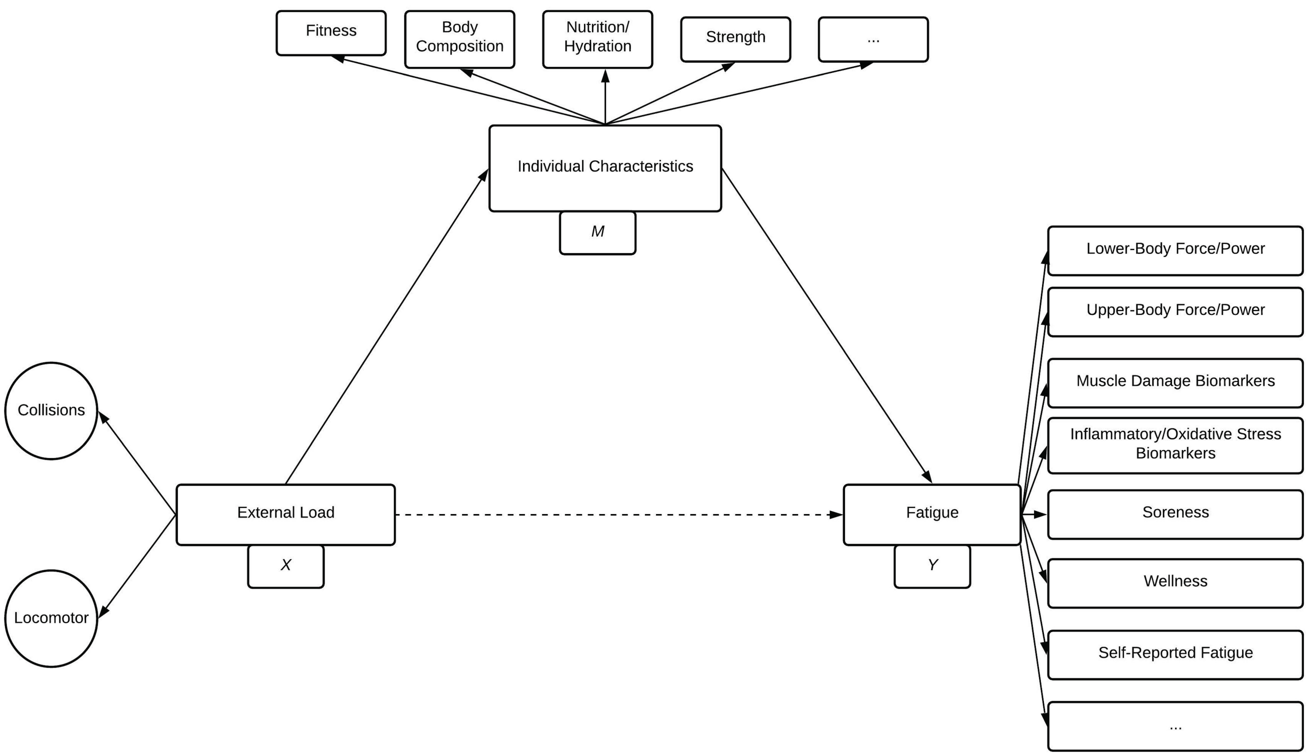

FIGURE 4 | A mediation path model representing the hypothesis that individual characteristics (*M*) mediate the effect of external load variables (*X*) on fatigue variables (*Y*). This mediation model describes external load, individual characteristics, and fatigue as latent variables and includes examples of functional measures which contribute to individual characteristics and fatigue. Single-headed arrows indicate an assumed causal relationship, and dashed arrows indicate the effect may be mediated. Ellipses represent other factors which may contribute but which are not included in the model.

and performance components of fatigue. As described, our suggested model is not intended in any way to supplant those conceptual approaches, but to offer an integrated example which has been contextualised to the specific characteristics of rugby outlined here, and elsewhere (Johnston et al., 2014a; Weaving et al., 2019b; Dalton-Barron et al., 2020; Till et al., 2020).

DISCUSSION

Conclusion

Current research suggests post-match fatigue (as indicated by changes in subjective and objective measures) occurs in the days following match-play which has implications on athlete readiness into the subsequent training week. Across the performance, biochemical, and self-reported assessments, changes from the pre-match baseline are observed almost immediately in the acute post-match period (i.e., ≤12 h post-match) which peak and typically recover in the 24–72 h post-match period (see "Practical Applications" section). Larger changes in neuromuscular performance were identified following match-play in rugby league, compared to rugby union, and rugby sevens. This indicates that the post-match fatigue response magnitude is greater in rugby league, and may be specific to the different demands of match-play in each rugby code. Given that post-match tissue biomarker responses were generally similar between the codes (e.g., rugby league and rugby union), this finding may be a function of the larger research base identifying post-match changes in neuromuscular fatigue for rugby league (n = 10 studies), compared to rugby union (n = 2 studies), or rugby sevens (n = 1 study).

Future Directions

Due to the added multidimensional, collision-based demands of rugby, this review focussed on the associations between these collision characteristics and fatigue type and time course which has remained, until now, uncharacterised. From this review, it is apparent that collision characteristics, such as collision frequency and intensity (**Figure 3**), are strongly related to the time course of fatigue measures at various time points in recovery. However, a common approach to understanding these relationships was through the use of univariate correlation analysis which includes the assumption that the individual variable is representing the complete construct [e.g., high-speed running (external load), countermovement jump force/power (fatigue)]. In **Figures 2**, **3**, we have demonstrated a conceptual reevaluation of the external load, internal load, and fatigue processes applied to rugby as being multidimensional and multivariate. When considering match-play external loads and fatigue as multidimensional latent constructs, multivariate data analysis techniques such as structural equation modelling (or singular value decomposition derived models) (Till et al., 2016; Weaving et al., 2017, 2019a), and the mediation of effects (Mooney et al., 2011) are therefore necessary to appropriately explore and identify these relationships.

A considerable advantage of our conceptualisation is that it offers testable hypotheses about the effects of collision and locomotor loads in rugby. For example, according to the model (**Figures 2**, **3**), the relative importance of fatigue types and time courses will differ depending on exposure to collision and locomotor external loads (Brustio et al., 2020; Lupo et al., 2021), and the individual characteristics of the athlete being exposed (Johnston et al., 2015). This can be conceptualised as a mediation relationship (Hayes, 2009), which is present and expanded on (**Figure 4**). In this mediation model, individual characteristics (such as strength, fitness, and body composition, etc.) may mediate the effects of external loads (including locomotor and collision loads) on measures of fatigue (**Figure 4**). Indeed, whilst prior research has shown differences in characteristics (such as strength and fitness) influence rugby post-match fatigue in junior athletes (Johnston et al., 2015), this research dichotomised the response data using a median split (i.e., stronger vs. less strong, fitter vs. less fit). This can be problematic as it is well established that dichotomising continuous data results in a loss of information, statistical power, and may result in spurious conclusions (Altman and Royston, 2006). Therefore, it remains to be determined if these (or related) factors, such as those discussed in **Figure 4**, are mediating this relationship. Taken together, future research should investigate the role of collisions on fatigue and recovery through both experimental models of isolated tackles and collisions (Usman et al., 2011; Burger et al., 2018), and through comparatively more sophisticated statistical approaches (such as mediation analysis and multivariate techniques) applied to observed match-play and recovery data (Mooney et al., 2011; Weaving et al., 2017, 2019a).

Given the abundance of subjective and objective methods that can be used to quantify post-match fatigue (**Figure 3**), practitioners need to consider which methods should be used to measure the return to homoeostasis depending on their given context. For example, methods such as force plates and monitoring of blood biomarkers of muscle damage and inflammation can be expensive and require specialised training and equipment (McLellan and Lovell, 2012; Chrismas et al., 2018; Kellmann et al., 2018). Further, tissue collection for biomarkers is invasive and may not be appropriate in certain settings. Therefore, whilst being informative as to the players' recovery state, such methods may not be feasible in certain contexts where resources and/or athlete access is limited. In these circumstances, practitioners may consider a cost-benefit analysis and instead choose to rely on subjective assessments of recovery, and low-cost objective methods such as mobile phone applications (Balsalobre-Fernández et al., 2015; Saw et al., 2016). However, the specific methods practitioners are currently using to quantify recovery from rugby match-play in specific situations are not known, and a consensus on which methods are recommended in each of these situations is needed. Such a broad consensus on the importance of recovery monitoring methods and their feasibility to implement would inform guidelines for practitioners to select strategies that suit their environment, and availability of time and resources. Prior work in sport has utilised consensus-building methods to produce return to play guidelines following hamstring injury in soccer (Van Der Horst et al., 2017), multi-sport concussion diagnosis (Reneker et al., 2015), and a tournament preparation framework for professional and amateur golf players (Pilgrim et al., 2018). Finally, this review was undertaken on research in men's rugby, and further research investigating women's rugby is necessary to determine the post-match recovery timelines, and to identify if fatigue measures are related to collision frequency or intensity in the women's game.

Limitations

A limitation of the available research has been the inability to properly account for isometric contractions which may influence muscle damage and in turn post-match fatigue. These types of contractions typically occur during scrums, wrestling, and other static movements which are associated with a high level of exertion, and due to the lack of movement of the players during these actions, are not quantified by microtechnology devices which rely on accelerometry (Naughton et al., 2020).

Whilst collisions are associated with prolonged post-match recovery, relationships between match collisions and post-match recovery at various time points have only been explored using univariate correlational analysis (such as Pearson's *r*) (McLellan and Lovell, 2012; Oxendale et al., 2016). Using this type of analysis in observational models is limited in that associations in such contexts cannot directly imply causation (Pearl, 2009), with causality indicated by a direct coupling of explanatory and response variables. Similarly, univariate analyses omit other factors which are expected to influence post-match recovery, including running workloads (**Figure 3**), playing time (Oxendale et al., 2016), and potential interactions effects between collision characteristics and external load factors (such as locomotor loads) (Johnston et al., 2014c,b; Dalton-Barron et al., 2020). For statistical analyses, the application of multiple, at times competing, univariate models increases the Type I (false positive) error rate which may produce spurious findings (Knudson and Lindsey, 2014). These factors have limited the ability to delineate the effects of collision characteristics from other confounding variables. Multivariate models and statistical mediation methods allow for the modelling of combined and interactive effects of the factors purported to influence post-match fatigue which have been outlined in this review.

Finally, during the post-match recovery time period rugby players typically apply various recovery strategies (i.e., cryotherapy, hydrotherapy, and compression garments, etc.) aimed at assisting the restorative processes toward homoeostasis (McLellan et al., 2011a; Webb et al., 2013). Whilst studies do note the application or cessation of these strategies (McLellan et al., 2011a; McLellan and Lovell, 2012), or account for these within their study design (Gill et al., 2006; Minett et al., 2010; Webb et al., 2013), this is not consistently reported, and therefore the effects of these strategies on post-match fatigue measures in the studies examined herein cannot be discounted.

Practical Applications

Published literature indicates that rugby match-play produces decrements in neuromuscular performance, altered biochemical markers, and increased perceived soreness in the post-match recovery period. From the research it appears there are three somewhat overlapping periods or "windows of fatigue" post-match in which changes are likely to be observed for practitioners to consider. Based on these findings, the initial period extending from immediately following match-play to 12–24 h post-match in which changes in the performance, biochemical, and subjective recovery measures are likely to be identified but have yet to reach their peak, can be termed the "acute" fatigue recovery period. The subsequent period of recovery extending from 24 to 72 h post-match can be termed the "residual" fatigue recovery period, wherein changes in these measures typically peak and thereafter subsequently return to at or near baseline levels. Athletes who train during this time may exhibit higher internal loads at a given external load (Impellizzeri et al., 2019). Finally, large changes evident beyond 72 h post-match are likely to be aberrant and this period can be termed the "persistent" fatigue recovery period. Practitioners should be aware that delayed recovery may be a symptom of more ongoing fatigue that could be due to an underlying issue (e.g., overtraining) associated with a "chronic-negative" effect (Jeffries et al., 2021), and that recovery delays beyond 72 h will negatively influence athlete readiness for subsequent training and competition and should be monitored as such. However, for the majority of athletes without a confounding issue, the typical 5–7 day recovery period between matches allows sufficient time to return to their individual baselines (McLean et al., 2010).

From a collision-perspective, the delays in recovery appear to strongly relate to the frequency and intensity of collisions players engage in during match-play, and there are position-specific differences in the magnitude and specificity (i.e., upper-body vs. lower-body) of these effects. Practitioners within rugby should be cognisant that the characteristics of the collision loads that their players undertake during match-play are likely to affect recovery post-match. Practitioners should therefore ensure they are appropriately monitoring match-related collision and locomotor loads alongside their individually selected subjective and objective recovery measures.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception, analysis, model conceptualisation, wrote, and revised the manuscript.

FUNDING

Funding for open access was provided through the University of the Sunshine Coast.

ACKNOWLEDGMENTS

The authors would like to thank Sarah Carter from the University of Sydney for assistance on the graphical design elements of **Figure 1** and acknowledge David Paul from University of New England for providing valuable feedback on an early draft of this manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ORIGINAL RESEARCH
published: 20 January 2022
doi: 10.3389/fphys.2021.803528

Repeated Interval Loughborough Soccer Passing Tests: An Ecologically Valid Motor Task to Induce Mental Fatigue in Soccer

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Most studies investigating mental fatigue (MF) in soccer utilized a computerized Stroop task to induce MF. However, the traditional key-pressing task has been challenged for its lack of ecological validity. The limited relevance to real-life soccer made it difficult to bridge the gap between the research and the applied setting. Therefore, a novel soccer-specific inducing task is in urgent need. This study compared a novel MF-inducing task in soccer with the Stroop task and investigated the impact of induced MF on cognitive and soccer-specific skill performance. A randomized, counterbalanced crossover design was employed. Fifteen well-trained male soccer players randomly participated in three MF-inducing tasks. Two of them were motor tasks consisting of 10 repeated interval Loughborough Soccer Passing Test (10xLSPT or LSPT) in clockwise passing order (10xC-LSPT) with each block starting every 2 min. The two tasks share the same movement pattern, but C-LSPT is considered to have lower cognitive demands. The third was the 20-min Stroop task (Stroop-20). MF was assessed immediately before and after each task by visual analog scale (VAS), the cognitive performance in a 3-min Stroop task, and the skill performance in one LSPT. Subjective MF increased similarly after 10xLSPT and Stroop-20 (+ 25.4 ± 10.3 vs. + 23.4 ± 10.8 AU, $p = 0.607$). The induced MF by 10xLSPT and Stroop-20 had no impact on cognitive performance and movement time but similarly affected in a significantly negative manner on penalty time (+ 5.9 ± 4.9 vs. + 5.4 ± 4.2 s, $p = 0.748$) and passing accuracy (–1.4 ± 1.5 vs. –1.0 ± 1.3, $p = 0.465$). Two motor tasks shared similar intensity, but 10xC-LSPT was inefficient to induce MF. The results showed that the 20-min repeated interval LSPT could induce a similar MF as the Stroop task. The induced MF had detrimental effects on soccer skill performance. The novel motor task is recommended for MF studies in soccer as an inducement task. Practitioners should be cautious about the prolonged cognitive-demanding skill section of the pre-match warm-up to avoid the negative effect of MF on the upcoming match. This motor task pattern could be followed as a supplementary training protocol.

Keywords: inducement, LSPT, soccer-specific, cognitive, skill

OPEN ACCESS

Edited by:
Athos Trecroci,
University of Milan, Italy

Reviewed by:
Dalton de Lima-Junior,
Federal University of Paraíba, Brazil
Damiano Formenti,
University of Insubria, Italy

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *28 October 2021*
Accepted: *15 December 2021*
Published: *20 January 2022*

Citation:
Bian C, Ali A, Nassis GP and Li Y (2022) Repeated Interval Loughborough Soccer Passing Tests: An Ecologically Valid Motor Task to Induce Mental Fatigue in Soccer. Front. Physiol. 12:803528. doi: 10.3389/fphys.2021.803528

INTRODUCTION

Soccer is an open-skill sport of high unpredictability, requiring players to have extraordinary physiological capacities combined with outstanding abilities in the areas of motor control, perception, and cognitive functioning (Romeas et al., 2016; Hans-Erik and Daniel, 2019). In matches, players have to maintain high attention levels over prolonged periods, perceive and interpret relevant information correctly, and then select the appropriate motor response under the constraints of time and space pressure (Baker et al., 2003; Nédélec et al., 2012). These soccer-specific tasks will cause mental fatigue (MF) in players (Coutts, 2016), a psychobiological state characterized by the feelings of tiredness and lack of energy during/after long periods of cognitive activity (Boksem and Tops, 2008; Marcora et al., 2009). Recently, there has been a growing interest in MF on soccer performance with negative impacts on physical (Smith et al., 2015, 2016a; Coutinho et al., 2018; Filipas et al., 2020; Trecroci et al., 2020), technical (Badin et al., 2016; Smith et al., 2016a, 2017; Greco et al., 2017; Filipas et al., 2020; Trecroci et al., 2020), tactical (Coutinho et al., 2017, 2018; Kunrath et al., 2018, 2020b), and cognitive (Smith et al., 2016b; Fortes et al., 2019, 2020; Gantois et al., 2020; Trecroci et al., 2020) performance of soccer players.

Most studies investigating MF in soccer utilized a computerized cognitive task (i.e., Stroop task) to induce MF (Kunrath et al., 2020a). Despite the effectiveness in inducing MF, traditional key-pressing tasks such as the Stroop task have been challenged recently due to its lack of ecological validity in this specific research field (Smith et al., 2018; Thompson et al., 2019). The limited relevance to real-life soccer made it difficult to bridge the gap between the research and the applied setting. Therefore, a novel motor task with ecological validity for soccer is in urgent need (Pinder et al., 2011; Travassos et al., 2012). Coutinho et al. (2017) have used a 20-min whole-body coordination task to induce MF. This motor task involved performing 7 different step exercises with a ladder while juggling a tennis ball to increase attentional and cognitive demands (Coutinho et al., 2017). Despite the success in inducing MF, this task might not be soccer-specific.

The Loughborough Soccer Passing Test (LSPT) is a multifaceted soccer-specific skill test to evaluate passing, dribbling, controlling, and decision-making abilities and has been shown to be a valid and reliable indicator of soccer skill performance (Ali et al., 2007). In this test, players are required to react to verbal random passing orders 16 times and execute skills quickly and accurately under time and space pressure (Ali et al., 2007). The finishing time (movement time) of one LSPT is less than 1 min. Relative intense cognitive and skill demands may cause a state of MF; if this happens, LSPT repeatedly performed for 20 min may be considered an effective ecological task for inducing MF in soccer players.

Therefore, the aim of this study was to explore a novel motor task for inducing MF in soccer with a better ecological validity by comparing the MF induced by repeated interval LSPT and the Stroop task. Secondarily, this study aimed to investigate the impact of induced MF on cognitive and soccer skill performance. Previous findings show that a 20-min motor task can induce the perception of MF of players to similar levels as responses to the Stroop task (Coutinho et al., 2017). Therefore, we hypothesized that 10-time repeated interval LSPT (20 min) would induce the same degree of MF as the 20-min Stroop task, and induced MF would negatively affect cognitive and soccer skill performance.

MATERIALS AND METHODS

Participants

The total sample size calculated by G*Power for a moderate effect size of 0.5 for performance indicators, an α of 0.05, and a power of 0.8 (1–β) was 42, with a minimum of 14 subjects in each group (3 sessions) in the counterbalanced crossover design. To account for any potential dropout, we recruited 15 well-trained male soccer players (age = 22.0 $\pm$ 2.5 years, height = 174.5 $\pm$ 6.5 cm, body mass = 68.2 $\pm$ 7.6 kg, body fat = 14.5 $\pm$ 2.9%, training experience = 8.1 $\pm$ 2.7 years, weekly training duration = 7.2 $\pm$ 1.0 h), including 5 forward, 5 midfielders, and 5 defenders. Participants were free of any known disease/injury/sleep disorder/smoking/medication. They were informed to sleep for at least 8 h the night before the testing sessions to avoid any cognitively demanding activity the day before the tests and to refrain from alcohol for 24 h and caffeine for at least 12 h before the tests (Craig et al., 2012). Players were instructed to consume water and the same light meal 1.5 h before every testing session. An information sheet was provided to the head coach and players at the beginning to explain the procedures involved, and they were informed that they could withdraw from the study at any time. Participants signed informed consent forms prior to commencing the study, and all procedures were approved by the Human Research Ethics Committee of the Shanghai University of Sport.

Study Design

A randomized, counterbalanced crossover design was employed. The purpose of this study was masked by telling players to compete with teammates for best performance. Participants visited an indoor parquet court with indoor soccer boots four times, with each trial separated by 48 h. The testing procedure is presented in **Figure 1**. The first visit was used for familiarization, with the following three visits as testing sessions. As illustrated in **Figure 1A**, all the sessions were comprised of (1) a warm-up, (2) pretests, (3) 20-min MF-inducing task, and (4) posttests. The tasks utilized to induce MF in session 1 and session 2 were repeated interval LSPT, with either a randomized order of passing [i.e., 10 repeated interval Loughborough Soccer Passing Test (10xLSPT)] or clockwise order of passing (10xC-LSPT), while the task in session 3 was the Stroop task (Stroop-20). After familiarization, players were divided into three groups randomly (denote: G1/2/3). Five players in each group conducted one session at a fixed day time (12:30–15:30) to minimize any potential effect of circadian rhythm (**Figure 1B**).

Procedures

During familiarization, players were exposed to all tasks and procedures together with the clear definition of MF.

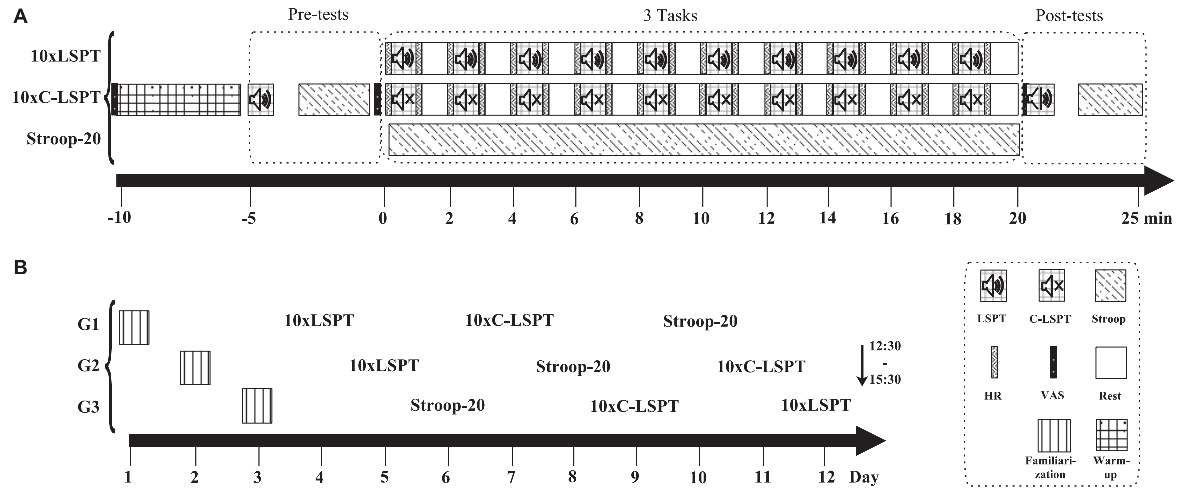

FIGURE 1 | Timelines of study procedures. **(A)** Timeline of test sessions; **(B)** timeline of study design; LSPT, Loughborough Soccer Passing Test; 10xLSPT, 10 repeats of Loughborough Soccer Passing Test; C-LSPT, modified Loughborough Soccer Passing Test in a clockwise passing order; 10xC-LSPT, 10 repeats of modified Loughborough Soccer Passing Test in a clockwise passing order; Stroop, Stroop task; Stroop-20, 20-min Stroop task; VAS, visual analog scale; HR, heart rate; G, group of participants.

Familiarization included performing at least 5 attempts of the LSPT under the instruction of examiners, 3 attempts of 3-min Stroop task (Stroop-3), and 3 attempts of sliding visual analog scale (VAS) until players were comfortable with the test procedures and their scores indicated that the learning effect had diminished (i.e., a plateau in scores) (Foskett et al., 2009; Smith et al., 2019).

The warm-up lasted 5 min and included ball passing and dynamic stretching. Players then finished one LSPT for assessing the initial soccer-specific skill performance and rested for 1 min, followed by a Stroop-3 for initial cognitive performance. After each MF-inducing task, one LSPT and Stroop-3 were conducted again for posttests. Players completed the VAS prior to the warm-up, immediately before and after the MF-inducing tasks. The first VAS score was used to assess the motivation of players for the upcoming session. The second and third VAS scores were used to quantify the baseline MF and the MF perceived after tasks.

Mental Fatigue Assessment Indicators

The assessments of MF in this study can be categorized as a subjective report, cognitive performance, and soccer-specific skill performance.

The changes of VAS values immediately before and after the MF-inducing tasks indicated the subjective perception of MF. The Stroop-3 in the pre- and posttest was used to assess the cognitive performance with the measures of response time and response accuracy. The LSPT in the pre- and posttest was used to evaluate soccer skill performance with the measures of movement time, penalty time, and passing accuracy (number of perfect passes).

Visual Analog Scale

The scale was plotted on a customized plastic ruler of 100 mm and anchored by the extreme limits of "minimum" (0) and "maximum" (100). One side was printed with a single straight line for participants while the other side was printed with the tick mark and number for examiners. Players were instructed to indicate "*What do you think of your perception of mental fatigue at this moment?*" by sliding an attached transparent vernier along the ruler from left to right until they were satisfied with the location. A subjective score (AU) was obtained by reading the millimeter distance from the left side of the scale to the vernier indicated by the player.

During familiarization and before every session, players were provided with the following definition of MF to support their subjective assessment: "*Mental fatigue, different from physical fatigue, is a psychobiological state characterized by feelings of tiredness and a lack of energy and is induced by prolonged periods of demanding cognitive activity*" (Boksem and Tops, 2008; Marcora et al., 2009; Smith et al., 2016b) (if confused, the examples of examination or studying for an extended period were given).

Motivation for upcoming sessions was also measured by the 100-mm VAS as reported by previous research (Smith et al., 2016b). Participants were asked "*How motivated are you to want to accomplish this test?*" before each session.

Stroop Task

The Stroop task in the pre- and posttest was the version reported by Badin et al. (2016) and Gantois et al. (2020). The MF-inducing task in session 3 was a continuous Stroop task lasting 20 min (Stroop-20). Players were instructed to sit on the bench at the corner of the court and to hold the tablet (iPad, Apple Inc., California, United States) to perform the Stroop task individually under the supervision of one examiner. Players were provided noise-canceling headphones to minimize distractions. Gestures were only given for indicating the start and end of the task. Stroop tasks were programmed

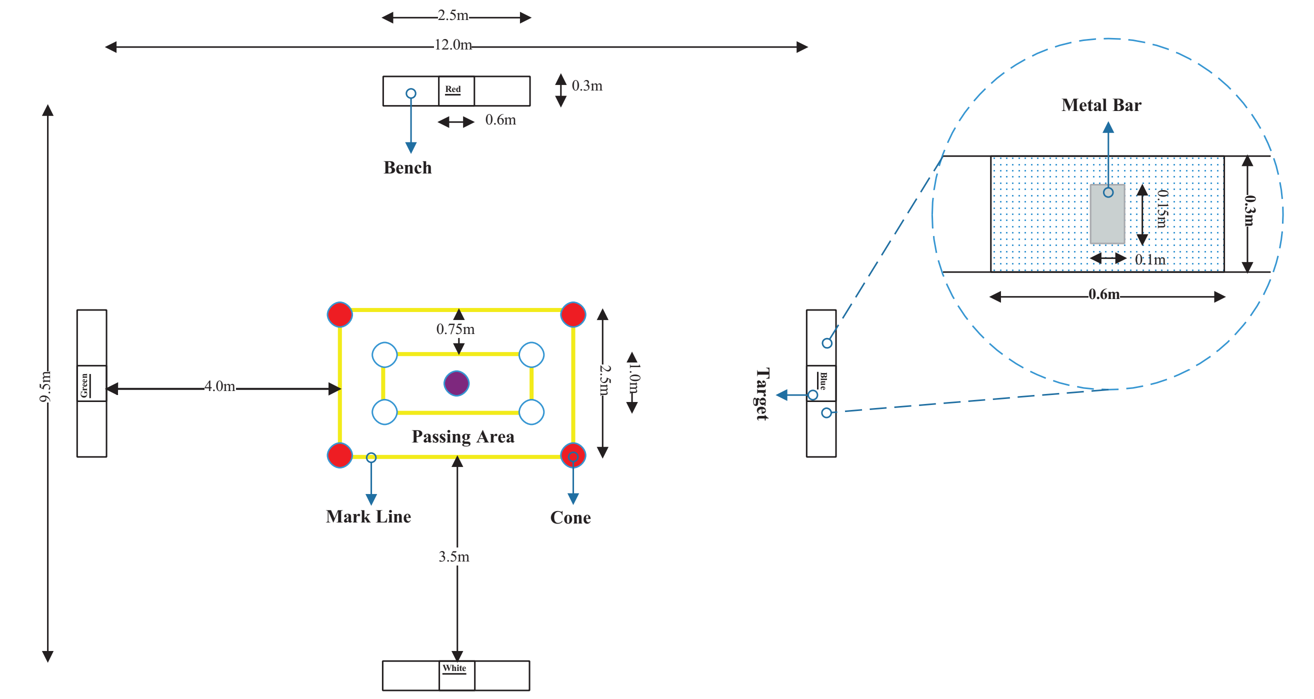

FIGURE 2 | Schematic representation of the Loughborough Soccer Passing Test (LSPT).

by E-Prime (Psychology Software Tools, PA, United States) and carried out on a full-HD screen (2,732 × 2,048 pixels, 12.9 inch) tablet; the virtual keyboard of the tablet was used for key pressing.

Colored words (red, blue, green, and yellow) were presented one at a time on the screen with a black background. Trials were arranged in a pseudorandom order with 50% of them being congruent (matched word and color) and 50% being incongruent, with all incongruent word–color combinations occurring with equal frequency. Players were required to respond to each trial by pressing one of the four keys on the bottom edge of the screen and then to choose the color of the word rather than its meaning. However, to increase task difficulty, if the word was displayed on screen in the color of red, the correct response was to press the key corresponding to the meaning of the word (Badin et al., 2016). The stimulus did not fade from the screen until a response was given. When the answer was correct, the stimulus disappeared, and a new one was set immediately, while any incorrect answer elicited a beep sound to prompt more accurate performance and a new stimulus subsequently appeared (Gantois et al., 2020). Moreover, to prevent the subjective slack during the task, we established the cutoff value of mean response time at 1.5 s, any slower data (<800 trials) were excluded for analysis. Players were motivated to perform faster than the cutoff value by the provision of an additional ¥50 RMB reward.

In the pre- and posttest, the 3-min short version of the Stroop task (Stroop-3) was used to assess the cognitive performance, with the measures of response time and response accuracy. Stroop-3 followed all the rules as Stroop-20, during which the player was asked to respond no less than 120 trials.

The Loughborough Soccer Passing Test

Players stood in the center of a rectangular passing area (2.5 × 4 m, **Figure 2**) and responded to an audible signal which indicated the direction of the pass. The four colored passing targets (0.6 × 0.3 m) were placed on rebound boards (benches), surrounding the rectangular playing area (12 × 9.5 m). Participants were required to complete the passes as quickly as possible while minimizing errors. Penalty time was added for errors (e.g., passing inaccuracy, playing from an incorrect zone, and poor ball control). Penalty time was deducted for a "perfect" pass (hitting the metal bar attached to the middle of the target), while movement time was the time to complete the test. One examiner was involved in calling out the order and timing the test. The second examiner was in charge of judging the errors and scoring the performance (refer to Ali et al., 2007 for details).

One standard LSPT involved 16 passes, using a randomized order of pass direction, as used in the pre- and posttests. The LSPT that was utilized to induce MF was either repeated interval LSPT (i.e., 10xLSPT) or repeated interval modified LSPT with clockwise order of passing (i.e., 10xC-LSPT). Since the finishing time of one LSPT was approximately 45 s, the 20-min MF-inducing process involved 10 repeats of the LSPT or C-LSPT, with each starting every 2 min. During the intervals between each LSPT and C-LSPT, the player rested for approximately 75 s in a standing posture.

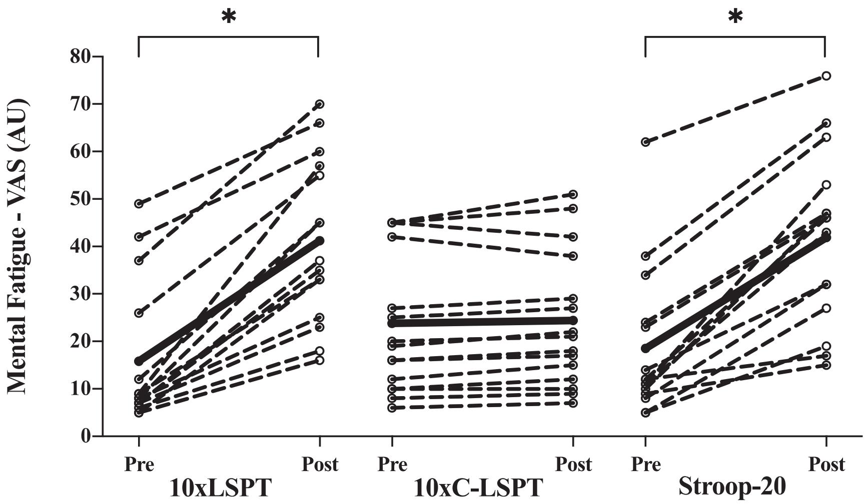

FIGURE 3 | Pre-post assessment of subjective mental fatigue. Circles and dashed lines indicate the data of individual participants, and black solid lines indicate the mean value. *Significant changes between pre- and posttest ($p < 0.05$); VAS, visual analog scale; 10xLSPT, repeated interval Loughborough Soccer Passing Test; 10xC-LSPT, repeated interval modified Loughborough Soccer Passing Test in clockwise order of pass direction; Stroop-20, 20-min Stroop task.

Intensity of Two Motor Tasks

Heart rate (HR) was monitored throughout utilizing an HR chest strap (Polar H10, Kempele, Finland) (sampling at a frequency of 2.4 GHz). HR immediately before and after each LSPT or C-LSPT during session 1 and session 2 was recorded for analyzing the physical activity (intensity) during the soccer-specific motor tasks. The Stroop task in session 3 was a static key-pressing task, the average HR of players was at their resting level according to the preexperiment, and therefore, this set of HR data was excluded for the analysis.

Statistical Analysis

All data are presented as mean ± SD unless otherwise stated. All statistical analyses were completed using SPSS Statistics, version 25 (IBM, NY, United States). Data were tested for normality and log-transformed when necessary. The motivation for the upcoming sessions was analyzed by a one-way ANOVA. Two-way repeated-measures ANOVA was performed to identify differences in HR, cognitive, and soccer skill indicators according to time and testing sessions (treatment) comparisons. Data sphericity was verified by Mauchly's test, and the Greenhouse-Geisser correction was adopted when this assumption was violated. Pairwise comparisons were assessed using the Bonferroni correction. The pre- and post-VAS scores were compared by paired t-tests. As a subjective indicator, players report different pre-VAS scores and have different feelings of MF every day. Therefore, we only considered the Time variable (intragroup) without the Treatment variable (intergroup) for VAS scores. The comparisons within sessions (time), as well as the comparisons between sessions (treatment), were also reported using mean difference ± SD. Posttest value minus pretest value: positive values meant an increase while negative values referred to a decrease over time. Significance was set at 0.05 (2-tailed) for all analyses. Partial eta squared effect sizes (η^2_p) were reported (< 0.04, no effect; 0.04–0.24, minimum practical effect; 0.25–0.63, moderate effect; ≥ 0.64, strong effect) (Ferguson, 2016).

RESULTS

Subjective Mental Fatigue and Motivation

Initial subjective MF that was assessed by VAS before the three sessions was similar (15.8 ± 15.0 vs. 23.8 ± 15.5 vs. 18.5 ± 15.6 AU, respectively; p = 0.359). There were similar significant increases in subjective MF (**Figure 3**) after 10xLSPT and Stroop-20 (+ 25.4 ± 10.3 vs. + 23.4 ± 10.8 AU; p = 0.607), but no significant change after 10xC-LSPT (p = 0.913). Players had similar motivation among the three sessions (87.8 ± 7.6 vs. 87.3 ± 7.0 vs. 86.9 ± 6.6 AU, respectively,; p = 0.937).

Intensity of Two Motor Tasks

There was no difference in mean HR throughout 10xLSPT (139 ± 14 bpm) and 10xC-LSPT (138 ± 14 bpm; p = 0.731; **Figure 4**).

Cognitive Performance

As illustrated in **Figure 5**, there was no main effect of time [F(1, 39) = 2.113; p = 0.154, η^2_p = 0.051] or treatment-time interaction [F(2, 39) = 0.543; p = 0.585, η^2_p = 0.027] in the response time of the Stroop-3 in the pre- and posttests of all three sessions. However, there was a main effect of treatment [F(2, 39) = 5.113; p = 0.011, η^2_p = 0.208] in the response time for Stroop-3, with lowest response time in 10xC-LSPT (0.93 ± 0.15 s; $p < 0.05$) relative to other two trials, but no differences between 10xLSPT and Stroop-20 (p = 0.249). *Post hoc* analysis showed similar steady trend over time in 10xLSPT (p = 0.733) and Stroop-20 (p = 0.990), while there was a significant decrease in 10xC-LSPT (−0.034 ± 0.05 s; p = 0.023, η^2_p = 0.337).

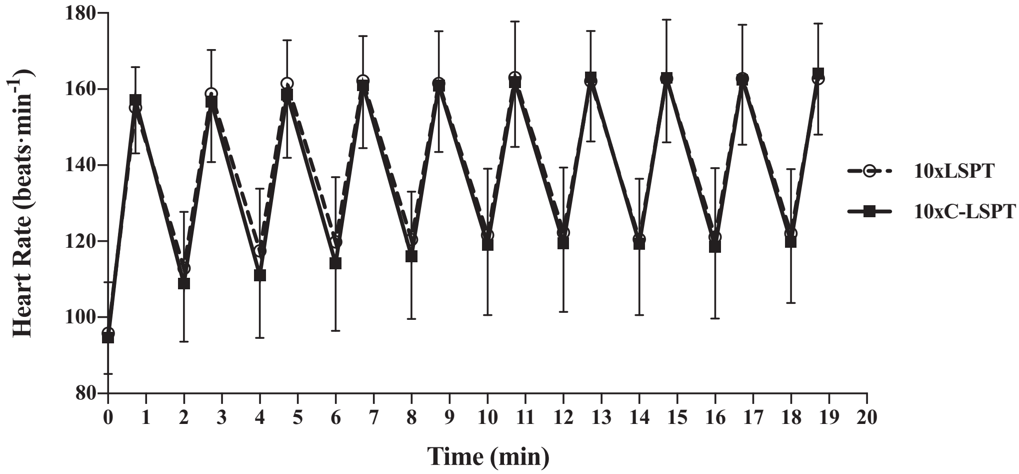

FIGURE 4 | Heart rate in two motor tasks. 10xLSPT, 10 repeats of Loughborough Soccer Passing Test; 10xC-LSPT, 10 repeats of modified Loughborough Soccer Passing Test in clockwise order of pass direction.

When analyzing the response accuracy of Stroop-3, no significant main effect of time [$F(1, 13) = 0.030$; $p = 0.866$, $\eta^2_p = 0.002$], treatment [$F(2, 26) = 1.480$; $p = 0.246$, $\eta^2_p = 0.102$], and treatment-time interaction [$F(2, 26) = 2.256$; $p = 0.144$, $\eta^2_p = 0.148$] was found. The pre-post accuracy remained unchanged, and the mean accuracy was similar (0.97 ± 0.02) in three sessions.

Soccer Skill Performance

As presented in **Figure 6**, the movement time of LSPT indicated no significant changes after two MF inducement tasks of 10xLSPT ($p = 0.983$) and Stroop-20 ($p = 0.098$). However, there was a significant decrease in movement time after 10xC-LSPT (–0.587 ± 1.040 s; $p = 0.046$; $\eta^2_p = 0.254$).

For penalty time of LSPT, significant main effect of time [$F(1, 42) = 28.462$; $p < 0.001$, $\eta^2_p = 0.404$] and treatment-time interaction [$F(2, 42) = 18.038$; $p < 0.001$, $\eta^2_p = 0.462$], but no significant main effect of treatment [$F(2, 42) = 1.519$; $p = 0.231$, $\eta^2_p = 0.067$] was found. There were similar significant increases in penalty time after 10xLSPT (+ 5.921 ± 4.923 s; $p < 0.001$; $\eta^2_p = 0.608$) and Stroop-20 (+ 5.373 ± 4.168 s; $p < 0.001$; $\eta^2_p = 0.640$). However, 10xC-LSPT caused a significant reduction in penalty time (–1.853 ± 2.314 s; $p = 0.008$; $\eta^2_p = 0.407$).

There existed a significant main effect of time [$F(1, 42) = 14.252$; $p < 0.001$, $\eta^2_p = 0.253$] and treatment-time interaction [$F(2, 42) = 8.246$; $p = 0.001$, $\eta^2_p = 0.282$], but no significant main effect of treatment [$F(2, 42) = 1.071$; $p = 0.352$, $\eta^2_p = 0.049$] for the amount of perfect passes (passing accuracy) of LSPT. The passing accuracy significantly decreased after 10xLSPT (–1.4 ± 1.502; $p = 0.003$; $\eta^2_p = 0.482$) and Stroop-20 (–1.000 ± 1.309; $p = 0.01$; $\eta^2_p = 0.385$), while there was no significant change after 10xC-LSPT ($p = 0.096$; $\eta^2_p = 0.185$).

DISCUSSION

The primary purpose of this study was to explore a novel motor task for inducing MF in soccer by comparing the MF induced by 20-min repeated interval LSPT and computerized Stroop task. The 20-min repeated interval LSPT, as a soccer-specific motor task, could induce a similar subjective MF as the 20-min Stroop task but with a better ecological validity. The novel task was designed to be intermittent, and it could represent the cognitive and soccer skill demands as real-life soccer play. Besides, the similar moderate intensity of the two motor tasks has excluded the interference of physical fatigue. The difference in cognitive demands accounts for the different efficiency of inducing MF. Apparently, the trait of this novel task was unexpected passing orders, which made it more cognitively demanding than the other motor task. The MF induced by the 20-min repeated interval LSPT and 20-min Stroop task had no similar effect on the cognitive and negative effect on soccer-specific skill performance. The findings supported the use of 20-min repeated interval LSPT as an MF-inducing task in soccer.

Subjective Mental Fatigue

The 100-mm VAS was utilized by numerous studies as a primary method to evaluate subjective MF (Smith et al., 2015, 2016a,b, 2017; Badin et al., 2016; Coutinho et al., 2017, 2018; Greco et al., 2017; Filipas et al., 2020; Kunrath et al., 2020b; Trecroci et al., 2020). In this study, the similar significant increases in subjective MF assessed by VAS after 10xLSPT and Stroop-20 and no significant changes after 10xC-LSPT indicated that the 20-min repeated interval LSPT could induce MF as well as the Stroop task.

The Stroop task needs important cognitive skills to achieve high performance as prolonged selective and sustained attention, as well as inhibitory control, which in turn causes a feeling of MF (Kunrath et al., 2020a). During LSPT, players need to perceive and interpret unpredictable passing orders and execute appropriate technical movements with the ball under time and space pressure (Ali et al., 2007). The test ideally includes perception-action couplings which represent the perceptual and information processing demands as in real-life gameplay (Pinder et al., 2011). Hence, the prolonged demand of decision-making and attention in 10xLSPT may have played a meaningful role in elevating

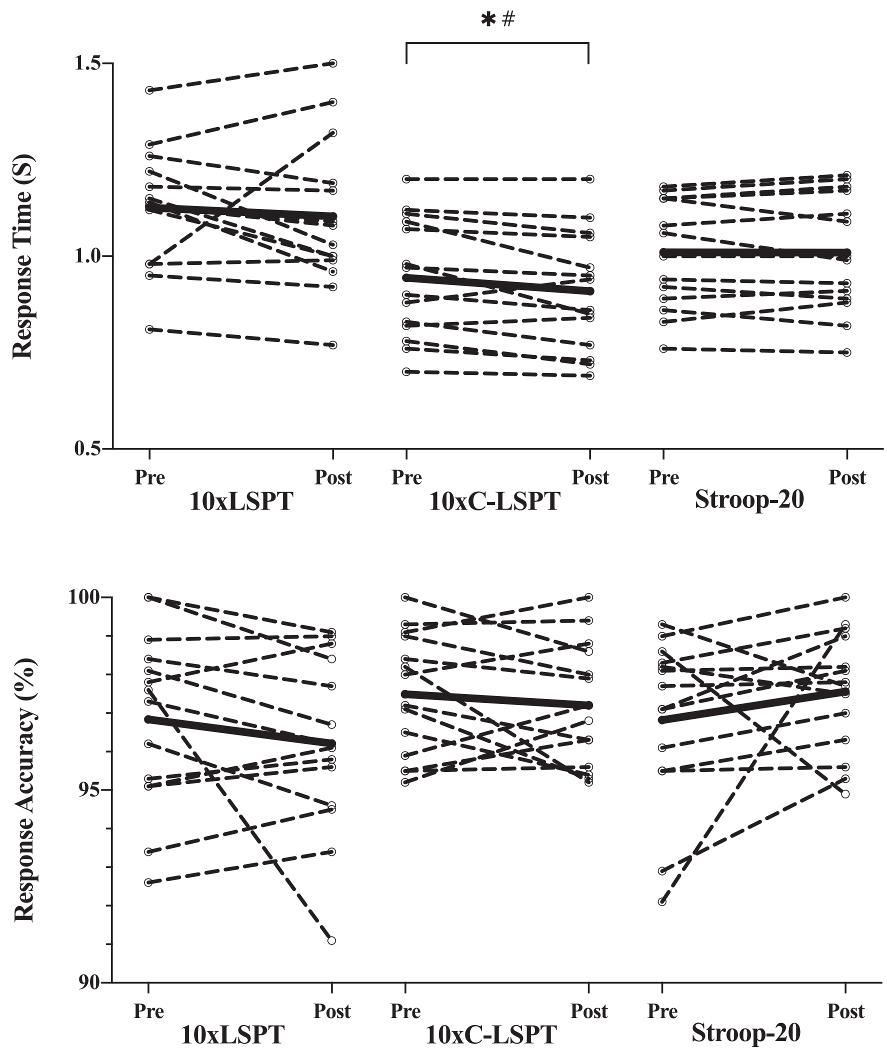

FIGURE 5 | Cognitive performance in pre- and posttests. The response time data of one player were excluded (> 1.5 s). Circles and dashed lines indicate the data of individual participants, and black solid lines indicate the mean value. *Significant changes when compared with pretest (p < 0.05); #moderate effect; 10xLSPT, repeated interval Loughborough Soccer Passing Test; 10xC-LSPT, repeated interval modified Loughborough Soccer Passing Test in clockwise order of pass direction; Stroop-20, 20-min Stroop task.

the perception of MF. Besides, the specialty of LSPT made it more ecologically valid than the Stroop task in the MF inducement in the soccer context. Comparatively, the C-LSPT was only a repetition of a series of expected movements in a fixed order, which required a reduced cognitive demand, and therefore inefficient to induce significant elevation of perceived MF in this duration.

The subjective MF in this study, as the key indicator, was indicated by VAS. Despite its well-proven acceptable validity and reliability, VAS should be applied carefully as the primary measurement of MF in soccer research for several potential biases (Thompson et al., 2019). First, the subjective report was based on the understanding of MF of players. A poor understanding may lead to an over- or underestimation of the actual perception. While repeating the definition of MF might increase the difficulty of masking the purpose of the research and then increase the acquiescence bias, which means players tend to agree with the questions asked by investigators (Watson, 1992; Thompson et al., 2019). Moreover, the feeling of boredom and physical fatigue could interfere with the self-assessment of MF (Thompson et al., 2019). As mentioned earlier, Coutinho et al. (2017) adopted light general aerobic exercises for the control condition, but the MF condition was induced by a whole-body coordination task. The significantly higher intensity (i.e., HR) of this mentally fatiguing task might have caused an interference from physical fatigue in that study.

For minimizing the aforementioned bias, we customized the VAS, reduced the exposure times of the scale, adopted a stricter control of motor task (set 10xC-LSPT), and broke down the motor tasks into blocks (Thompson et al., 2019) by setting up intervals to prevent boredom and exhaustion. Players were blinded for the vernier readings, and the interval of pre-post

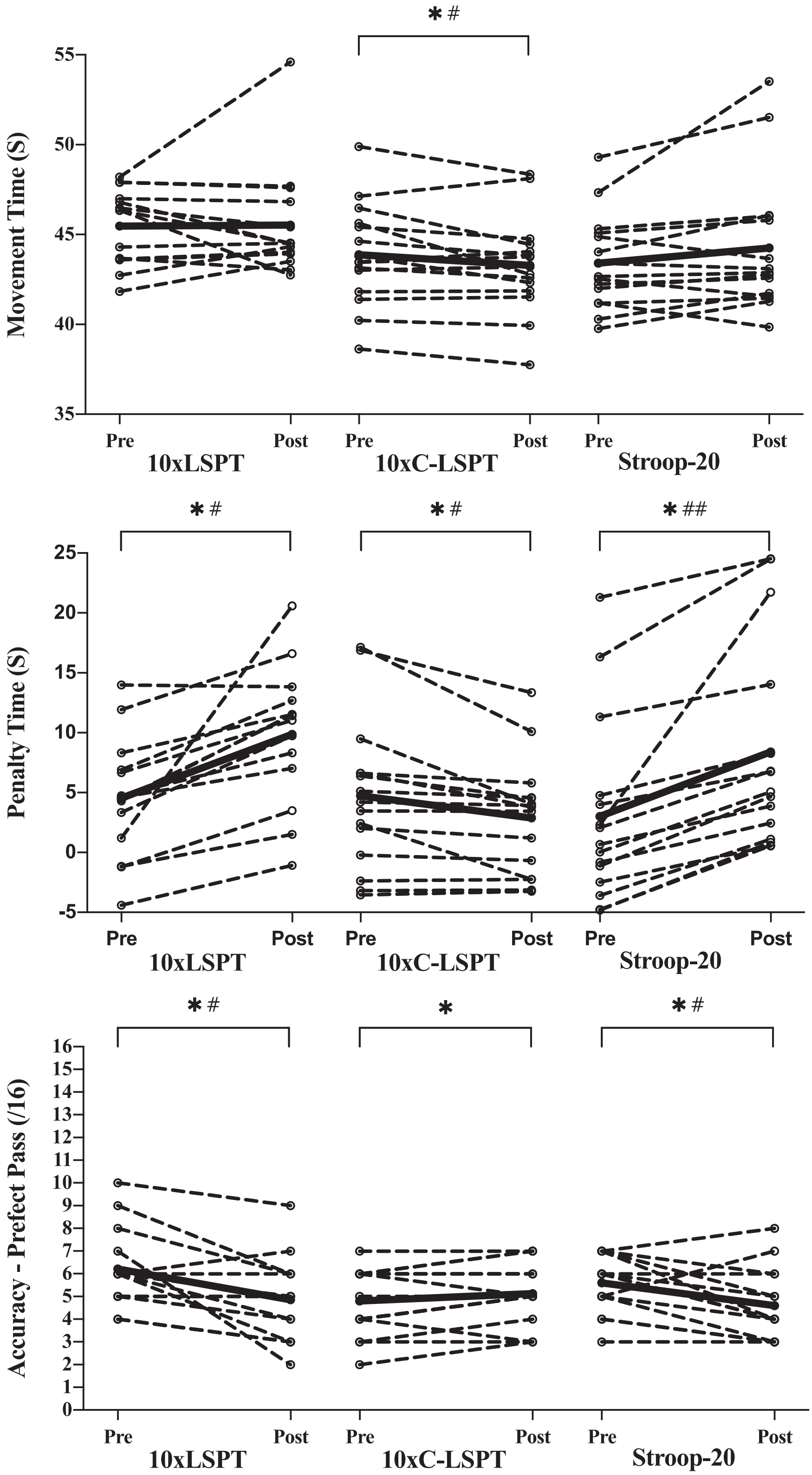

FIGURE 6 | Assessment of soccer skill performance. Circles and dashed lines indicate the data of individual participants, and black solid lines indicate the mean value. *Significant changes when compared with pretest ($p < 0.05$); #moderate effect; ##strong effect; the response time data of one player were excluded (>1.5 s); 10xLSPT, repeated interval Loughborough Soccer Passing Test; 10xC-LSPT, repeated interval modified Loughborough Soccer Passing Test in clockwise order of pass direction; Stroop-20, 20-min Stroop task.

reports was considered to be long enough (20 min). Combined with the similar intensity of two motor tasks (**Figure 4**), we concluded that the physical components had been controlled in this study. The extent of physical fatigue after two motor tasks did not account for the difference in the subjective MF of players.

Cognitive Performance

It has been suggested that performance decrement during a cognitive task is the gold standard measure of MF (Hockey, 2011). Short versions of the Stroop task (50–62 stimuli, 2–3 min) have been validated and applied as tools for assessing MF by detecting the changes in response time and accuracy (Fortes et al., 2019, 2020; Gantois et al., 2020). In this study, we also adopted the 3-min Stroop task to assess MF. Our findings showed that the cognitive indicators remained steady after 10xLSPT and Stroop-20, while the response time after 10xC-LSPT showed a significant decrease with a moderate effect.

The unchanged outcome of response accuracy during three sessions supports the earlier study by Gantois et al. (2020). However, the response time was kept steady after the inducement of MF, which was not in line with previous findings (Fortes et al., 2019, 2020; Gantois et al., 2020). Although the reduction in cognitive performance is an indication of MF (Van Cutsem et al., 2017), it is suggested that cognitive performance does not necessarily need to worsen since compensatory effects may occur (i.e., an increase in brain activity and/or motivational component) (Van Cutsem et al., 2017). In fact, the high levels of motivation (approximately 87 of 100 AU) of players in this study may allow maintenance of cognitive performance under fatiguing conditions (van der Linden, 2011). Another plausible reason accounting for this discrepancy might be the slower baseline values of response time in this study (1.06 ± 0.2 s) than previous ones [0.9 ± 1.7 s (Fortes et al., 2019); 0.3 ± 0.2 s (Fortes et al., 2020); less than 0.6 s (Gantois et al., 2020)]. Although the participants in other abovementioned studies were at a professional level, high-level players tend to demonstrate better cognitive abilities than their low-level counterparts (Formenti et al., 2020; Athos et al., 2021), and the fastest response time in 10xC-LSPT (0.93 ± 0.15 s) indicated the possible underestimation of the response speed and potential slack of these well-trained collegiate players in 10xLSPT and Stroop-20.

Soccer Skill Performance

The novel motor task (10xLSPT), similar to the 20-min continuous Stroop task, had a significant detrimental effect on technical ability and passing accuracy but no clear effect on movement time of LSPT. Where there were significant effects, the effect sizes were moderate to strong (technical ability: $\eta^2_p = 0.608–0.640$; passing accuracy: $\eta^2_p = 0.385–0.482$). These results of LSPT were in line with previous studies (Smith et al., 2016a, 2017; Greco et al., 2017; Filipas et al., 2020).

Speed and accuracy are two fundamental aspects of skill performance in soccer. Due to a speed-accuracy trade-off (Lorist et al., 2000), studies showed that players tended to keep the speed at the expense of accuracy (Smith et al., 2016a). Based on the conceptual model developed by Smith et al. (2018) outlining a potential mechanism of MF, cognitively demanding tasks keep activating the anterior cingulate cortex, likely leading to elevated adenosine, and a corresponding decrease of dopamine in this brain region, which then causes impairments to many executive functions including attentional allocation (Smith et al., 2018). Mentally fatigued players would suffer from the limited amount of attention resources. Therefore, they may have found it easier to ensure the completion of LSPT than focus on the skill quality (Smith et al., 2016a; Kunrath et al., 2020a).

The 10xC-LSPT led to a positive effect on skill performance relative to the two mentally fatiguing tasks (10xLSPT and Stroop-20), and this could be interpreted as an increase in technique proficiency. The C-LSPT shared the same movement pattern as LSPT but with less mental demand. Repeating the sequences of movements in C-LSPT might promote the execution speed in posttest LSPT. There exists a close interplay of motor and cognitive skills in soccer players (Hans-Erik and Daniel, 2019). The attention window was positively correlated with dribbling skills, and working memory was positively associated with dribbling, control, and juggling skills (Athos et al., 2021). The series of movements in this predictable motor task might have the cognitive functions of activated players but without inducing cognitive fatigue, contributing to the enhancement of skill performance during the posttest. Logically, it is possible to utilize the motor task pattern as a supplementary training protocol for warm-up and re-warm-up in the future.

Limitations and Future Directions

First, the participants in this study were collegiate players, whether the findings could be extended to professional players is unclear. Considering that professional players are believed to be more resistant to MF (Smith et al., 2018), further study could expand the task to a cohort of higher performance levels. Second, despite the strict control, the MF was primarily assessed with VAS which may have been influenced by the acquiescence bias (Watson, 1992). More objective psychophysiological measures of MF [e.g., electroencephalography (EEG)] are encouraged in the future (Thompson et al., 2019). Third, the cognitive performance test (Stroop-3) may be very easy for these collegiate players due to the lack of stricter time restrictions. A more sensitive and difficult cognitive performance test should be applied in the future.

CONCLUSION

The 20-min repeated interval LSPT is able to induce a similar MF as the Stroop task but with a better ecological validity. The MF induced by the repeated interval LSPT had a similar impact as the Stroop task on cognitive and soccer-specific skill performance. The induced MF had detrimental effects on skill stability and passing accuracy. The novel motor task is recommended for studies in soccer when the inducement of MF is required. Practitioners should be cautious about the prolonged cognitive-demanding skill section of pre-match warm-up to avoid the negative effect of MF on the upcoming match. This motor task pattern could be followed as a supplementary training protocol.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Human Research Ethics Committee of Shanghai University of Sport. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CB involved in the design of the study, data collection, analysis, and interpretation, as well as in the draft of the main document. YL worked on the data design, experiment organization, and manuscript content revision. AA and GN helped in the manuscript draft, design, data analysis, and revised them critically. All authors approved this final version and agreed to be accountable for all aspects of the work.

FUNDING

This study was supported by the Ministry of Science and Technology of the People's Republic of China (2018YF0300901), the Shanghai Science and Technology Commission (TP2017063), and the China Institute of Sport Science (Basic 20-37).

ACKNOWLEDGMENTS

We appreciate the collaboration of the players and their coaches.

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frontiers in Physiology

ORIGINAL RESEARCH
published: 02 February 2022
doi: 10.3389/fphys.2022.768906

Bilateral Deficit in Countermovement Jump and Its Influence on Linear Sprinting, Jumping, and Change of Direction Ability in Volleyball Players

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We investigated the association between bilateral deficit (BLD) in the countermovement jump (CMJ) and change of direction (CoD) performance, CoD deficit, linear sprint, and approach jumping task. The participants (47 young volleyball players; age: 20.8 ± 3.8 years) performed bilateral and single-leg CMJs, modified *T*-test, 505 CoD test, 25-m sprints (with 5, 10, and 15 splits), and vertical approach jumps. The CoD deficit was also calculated from the 505 test and 10 m split time. BLD was calculated from CMJ jump height, peak power, and phase-specific force impulses (FIs). Several small to moderate statistically significant correlations (r = 0.42–0.49) were found between BLD and 505 times (7 correlations), sprint times (4 correlations), CoD deficit (1 correlation), and approach jump (1 correlation). *T*-test performance was not correlated with BLD variables (r = −0.15–0.22). The direction of the correlations indicated that the larger BLD is associated with superior performance, with the exception of 1 correlation for 505 times for the left leg and 1 for CoD deficit for the left leg. However, these two variables showed unacceptable reliability. Our results suggest that BLD could be useful in making decisions about the amount inclusion of unilateral training for volleyball players.

Keywords: bilateral deficit, agility, vertical jump, 505 test, approach jump

OPEN ACCESS

Edited by:
*Alessio Rossi,
University of Pisa, Italy*

Reviewed by:
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University of Milan, Italy
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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *01 September 2021*
Accepted: *04 January 2022*
Published: *02 February 2022*

Citation:
Pleša J, Kozinc Ž and Šarabon N (2022) Bilateral Deficit in Countermovement Jump and Its Influence on Linear Sprinting, Jumping, and Change of Direction Ability in Volleyball Players. Front. Physiol. 13:768906. doi: 10.3389/fphys.2022.768906

INTRODUCTION

The term bilateral deficit (BLD) is describing the observation that muscle force generated during maximal bilateral actions is lower than the sum of forces of the left and right limb generated during unilateral contractions (Škarabot et al., 2016). The BLD has been the subject of extensive research (Jakobi and Chilibeck, 2001; Škarabot et al., 2016), and several factors and underlying mechanisms of BLD have been suggested [for review, refer to Škarabot et al. (2016)]. Most often, the BLD has been assessed through isometric or dynamic single-joint contraction; however, it is also observed during ballistic actions, such as various types of vertical jumps (Soest et al., 1985; Bobbert et al., 2006; Pain, 2014). The BLD in single-joint tasks is currently attributed to neural mechanisms (Škarabot et al., 2016), such as interhemispheric inhibition, while a substantial proportion of the variance in BLD in jumping has been explained by mechanics (Bobbert et al., 2006). During bilateral jumps, the muscles shorten with higher velocity, which means that the force output is inevitably lower, which also translates into less joint work per leg (Bobbert et al., 2006). While the majority of the studies aimed to explain the underlying mechanisms of BLD, its potential relevance for athletic performance has been somewhat neglected. Previous studies have demonstrated that resistance training emphasizing bilateral actions decreases the BLD, and the training involving unilateral exercises increases it (Häkkinen et al., 1996; Taniguchi, 1998; Janzen et al., 2006; Beurskens et al., 2015). BLD seems to be very plastic, namely, an opposite phenomenon, termed bilateral facilitation, has also been observed in bilaterally trained athletes, such as Olympic weightlifters (Howard and Enoka, 1991). Jumping tasks seem particularly promising in regard to performance, as they probably encompass both neural and mechanical aspects of BLD (Bobbert et al., 2006; Škarabot et al., 2016). If BLD is related to sports performance, it could be used to guide training-related decision-making, such as preferential inclusion of bilateral or unilateral exercises into the training programs of athletes.

To date, only five studies have examined the relationship between BLD and athletic performance (Bračič et al., 2010; Bishop et al., 2019; Ascenzi et al., 2020; Kozinc and Šarabon, 2021; Nicholson and Masini, 2021). It was found that the lower BLD in the countermovement jump (CMJ) was related to higher peak forces measured at the rear leg during sprint start ($r = -0.63$) and higher total force impulse (FI) ($r = -0.55$) (Bračič et al., 2010). In other words, sprinters with higher BLD produced lower rear leg forces and lower total FI, suggesting that BLD should be minimized for optimization of sprint start. However, no performance data, such as sprint times, were obtained in this study. Two subsequent studies reported that higher BLD could be positively related to change-of-direction (CoD) ability (Bishop et al., 2019; Kozinc and Šarabon, 2021). Higher BLD could reflect better neuromuscular capacity in unilateral tasks compared with bilateral tasks. Given that CoD tasks consist of a series of unilateral actions, the abovementioned associations seem reasonable. However, in two other studies, no relationship was found between BLD in CMJ and linear sprint performance or CoD performance (Ascenzi et al., 2020; Nicholson and Masini, 2021). Overall, the literature suggests that BLD could be related to athletic performance, especially to CoD tasks. However, two of the previous studies were not conducted on athletes (Bishop et al., 2019; Nicholson and Masini, 2021), and only two studies (Bishop et al., 2019; Ascenzi et al., 2020) included CoD deficit as a metric of performance. It is well known that the performance of the CoD tasks is heavily influenced by linear acceleration and sprinting ability (Nimphius et al., 2016). Recently, the CoD deficit was suggested as an approach to obtain a more isolated measure of CoD ability and limit the effect of the acceleration and linear sprinting ability (Nimphius et al., 2016). However, the relationship between CoD deficit and BLD remains unexplored. Moreover, the relationship between BLD and sport-specific tasks has not been investigated to date, and none of the aforementioned studies have been conducted on volleyball players.

The purpose of this study was to examine the relationship between BLD, derived from CMJ variables, and CoD performance (*T*-test and 505 test), CoD deficit, linear sprinting ability, and approach jump performance, on a sample of young male volleyball players. Volleyball gameplay involves repeated explosive efforts in multiple directions (Hedrick, 2007). In addition, approach jumps are pivotal for attacking actions in volleyball (Forthomme et al., 2005). We hypothesized that larger BLD in CMJ variables would be associated with better CoD performance (i.e., shorter CoD task times and lower CoD deficit) (Bishop et al., 2019; Kozinc and Šarabon, 2021), as well as better sprint and approach jump performance. In addition to jumping height (JH) and peak power (PP), we also used phase-specific (i.e., braking, propulsive, and total positive) FI outcomes for BLD calculation, as specific abilities, such as eccentric strength, which are known to be crucial for sport-specific performance (Chaabene et al., 2018). Considering the particular importance of eccentric strength for CoD performance (Chaabene et al., 2018), we hypothesized that BLD calculated from braking phase FI presents a higher correlation with CoD performance.

MATERIALS AND METHODS

Participants

For this study, we recruited 47 young male volleyball players (age: 20.8 ± 3.8 years; body height: 187.4 ± 7.8 cm; body mass: 80.8 ± 8.8 kg). All the players have been competing in the 1st or 2nd division of the national league. They reported regular participation in training for 10.6 ± 4.6 years and to attend 5.6 ± 1.5 training sessions per week. They also reported to perform full-body resistance exercises regularly. The inclusion criteria were the absence of injuries in the previous 6 months and the absence of any other medical diseases. All participants were thoroughly informed about the experimental procedures and signed informed consent before proceeding with the testing. For underage participants, their parents or legal guardians signed the consent on their behalf. The experiment was approved by the Republic of Slovenia National Medical Ethics Committee (approval number: 0120–99/2018/5) and was conducted in accordance with the Declaration of Helsinki.

Study Design

This was a cross-sectional study, conducted in a single visit. The participants had been routinely performing the testing procedures; therefore, no familiarization session was conducted. The participants performed a warm-up, consisting of 10 min of light running on an indoor track, 5 min of dynamic stretching, and 5 min of bodyweight resistance exercises (i.e., squats, lunges, and push-ups). Then, they completed (a) assessments of vertical jump on a force plate (bilateral and unilateral CMJ), for the purpose of calculating BLD and (b) performance tests (25-m linear sprint, modified *T*-test, 505 test, and vertical approach jump). The breaks between the tasks were at least 5 min. The order of the performance tasks was randomized. In all tasks, the average of the repetitions was considered for further analyses.

Countermovement Jump Assessment

The CMJs were performed on a piezoelectric force plate (Kistler, model 9260AA6, Winterthur, Switzerland). The participants performed 2–3 warm-up trials for each jump (bilateral and unilateral). Each jump was performed 2 times (6 repetitions in total), with 1 min recovery between trials. The hands were placed on the hips at all times. The participants were instructed to perform an explosive counter-movement to the self-selected depth and to jump as high as possible. For the unilateral CMJ, the non-tested leg was slightly flexed at the knee and was not allowed to be touching the tested leg and not allowed to swing during the jump. Both legs were tested unilaterally in alternating order.

Ground reaction force data were recorded at a sampling rate of 1,000 Hz. The signals were automatically processed using the software of the manufacturer (MARS, Kistler, Winterthur, Switzerland) by a moving average filter with a 5 ms window. The FI (force multiplied by time) at each time point (1 ms) was divided by the mass of the participant to determine the change in velocity, which was then added to the velocity of the system to compute a new instantaneous velocity. The JH was calculated based on the takeoff velocity. Instantaneous power was calculated as the product of force and velocity, and the PP was considered as one of the outcome variables. In addition to JH and PP, we considered several phase-specific FI outcome (defined as an integral of force with respect to time) metrics in specific phases of the jump. These phases included the unweighting phase, the braking phase, and the propulsion phase. In addition, the total positive FI (the FI in braking and propulsion phase combined) was also calculated. The BLD_{CMJ} was calculated using the following equation (Škarabot et al., 2016):

$$BLD\ (\%) = \left(100 \times \frac{Bilateral}{Unilateral\ left + Unilateral\ right}\right) - 100$$

Change-of-Direction Performance

The change-of-direction (CoD) assessment involved two tests (modified T-test and 505 test). For both tests, we used single-beam laser timing gates (Brower Timing Systems, Draper, UT, United States), which were positioned at the level of greater femoral trochanter for each participant and recorded the times to the nearest 0.001 s. The participants began each task 30 cm behind the start line in order to prevent early triggering of the timing gates. First, a modified T-test was conducted. In brief, the modified T-test maintains the number and the directions of the traditional T-test, but with approximately twofold shorter total distance [refer to Sassi et al. (2009) for details]. The participants started the test at their own discretion. Two warm-up repetitions with submaximal effort were performed first, followed by three test repetitions, with 2 min recovery in between. Then, the 505 test was performed, using the same timing gates. The participants were instructed to sprint to a line that was marked 15 m from the start line (with timing gates positioned 10 m from the start line). They were instructed to plant the left or the right foot on the line, turn for 180° and sprint back 5 m through the timing gates again. Three repetitions were performed for each leg in alternating order, with 2 min recovery between the repetitions. In addition to the total times of the 505 test, we calculated the CoD deficit for each leg, by subtracting 10 m sprint times (refer to the "Linear Sprint" section) from the 505 scores (Nimphius et al., 2016).

Linear Sprint

Using five pairs of timing gates (the same as above), we collected 0–5, 0–10, 0–15, and 0–25 m sprint times. As with the CoD trials, the participants began each sprint 30 cm behind the start line. A standing start was used, and subjects were free to choose their front leg, which was kept constant across repetitions. Subjects were instructed to sprint from the start line through all sets of timing gates as fast as possible. Five trials were performed, and the recovery time between repetitions was set at 2 min. Sprint split times were used as performance indicators, and the 0–10 m time was also used to calculate the CoD deficit (refer to the "Change-of-Direction Performance" section).

Vertical Jumps With Approach

Vertical jumps with approach were performed at maximum effort, simulating a spike jump in volleyball (Sorenson et al., 2010). First, standing reach was measured with the dominant arm reaching overhead, while participants were facing the wall. Jumping reach was measured with a measurement tape placed on the basketball board. Before each jump, participants marked their fingertips with chalk to more accurately determine the jump reach. The difference between the reach from standing and the jump reach represented the JH. Using a spike approach, the participants jumped for height and touched as high as possible on the measuring tape at the basketball board. Since all participants were well familiar with the test, they were instructed to perform the jumps in a way that they found most convenient, similar to their personal technique during volleyball practice. Each participant performed two warm-up trials and three testing attempts, with 1 min recovery in between. Measurements were recorded to the nearest 1.0 cm.

Statistical Analysis

Statistical analyses were performed using SPSS (version 25.0, SPSS Inc., Chicago, IL, United States). Descriptive statistics are reported as mean ± SD. Normality of data distribution was verified using Shapiro-Wilk tests. Correlations among BLD variables and performance variables were assessed with Pearson's correlation coefficients and interpreted as negligible (<0.1), weak (0.1–0.4), moderate (0.4–0.7), strong (0.7–0.9), and very strong (>0.9). Reliability among repetitions was assessed with intra-class correlation coefficients (ICC) (Koo and Li, 2016) and typical error (Hopkins, 2000), expressed as coefficient of variation (CV). The reliability was considered acceptable when the ICC was >0.75 and CV was <10% (Shechtman, 2013). The threshold for statistical significance was set at $p < 0.05$.

RESULTS

Descriptive Statistics and Reliability

The descriptive statistics and reliability values for all performance variables are shown in **Table 1**. It is noted that only data for the left leg for unilateral CMJ are shown, as there were no differences between the legs in terms of reliability. All performance variables had acceptable absolute reliability (CV = 2.09–9.68%). Relative

TABLE 1 | Descriptive statistics and reliability for all outcome variables.

Task group	Outcome measure	Trial 1		Trial 2		Trial 3		Reliability	
		Mean	SD	Mean	SD	Mean	SD	ICC	CV
Performance indicators	Approach jump (cm)	68.91	16.53	70.21	16.35	69.80	16.65	0.99	2.64
	T-test (s)	5.51	0.35	5.47	0.37	5.44	0.38	0.89	2.31
	505 left (s)	2.42	0.21	2.37	0.16	2.38	0.20	0.68	4.56
	505 right (s)	2.37	0.15	2.34	0.18	2.34	0.15	0.78	3.39
	CODD left (s)	0.60	0.16	0.58	0.14	0.59	0.19	0.67	15.5
	CODD right (s)	0.57	0.15	0.53	0.14	0.55	0.15	0.87	9.68
	5 m (s)	1.56	0.10	1.55	0.10	1.55	0.10	0.89	2.19
	10 m (s)	2.27	0.21	2.29	0.15	2.29	0.15	0.81	3.36
	15 m (s)	2.98	0.24	2.99	0.23	2.97	0.20	0.85	2.98
	25 m (s)	4.25	0.36	4.26	0.29	4.27	0.30	0.92	2.09
Bilateral CMJ	Jump height (m)	0.39	0.08	0.39	0.09	/	/	0.97	3.83
	Peak power (W/kg)	55.04	9.13	54.40	9.11	/	/	0.96	3.37
	FI (Breaking)	110.47	21.84	117.99	21.02	/	/	0.85	7.28
	FI (Propulsion)	216.21	38.29	216.25	38.83	/	/	0.99	2.00
	FI (Total positive)	327.82	56.51	335.45	57.24	/	/	0.97	2.81
Unilateral CMJ	Jump height (m)	0.19	0.06	0.19	0.06	/	/	0.96	6.83
	Peak power (W/kg)	35.20	18.69	35.24	18.51	/	/	0.99	4.95
	FI (Breaking)	67.18	18.97	71.89	18.60	/	/	0.87	9.89
	FI (Propulsion)	154.09	46.79	154.61	46.92	/	/	0.99	3.39
	FI (Total positive)	219.58	52.33	225.72	52.30	/	/	0.97	4.18

FI, force impulse; ICC, intra-class correlation coefficient; CV, coefficient of variance (typical error expressed as a % of mean). Note that only two trials were performed for jumping tasks. In addition, the 4th and 5th repetitions for the sprint trials are omitted on purpose to preserve the coherence of the table.

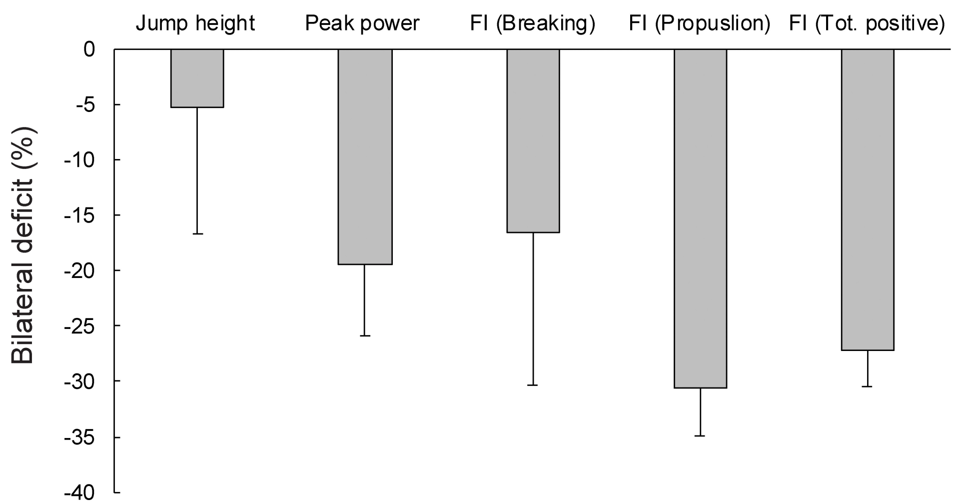

FIGURE 1 | The bilateral deficit in countermovement jump variables. FI, force impulse.

reliability was also acceptable for most performance variables, with the exception of 505 test time for the left side (ICC = 0.68) and COD deficit for the left side (ICC = 0.67). The CMJ variables all showed acceptable relative (ICC = 0.85–0.99) and absolute reliability (CV = 2.0–9.98%).

Bilateral Deficit

The magnitude of the BLD variables is shown in **Figure 1**. In addition to the means and SDs, the minimum and maximum values, as well as the number of participants who showed BLD and bilateral facilitation are shown in **Table 2**. On average, the JH showed the lowest BLD (−5.24 ± 11.44%), with 9 out of 47 participants showing bilateral facilitation. For other variables, the mean BLD was higher, ranging from −30.57 to 16.47% (refer to **Table 2** and **Figure 1** for details). For the braking phase FI, 5 out of 47 participants showed bilateral facilitation, whereas, for the remaining variables, only 1 participant showed bilateral facilitation.

TABLE 2 | Descriptive statistics for BLD outcomes.

	Mean	SD	Min	Max	Showing BLD	Showing BLF
BLD jump height	−5.24	11.44	−19.92	39.43	38	9
BLD peak power	−19.46	6.42	−34.14	−4.67	46	1
BLD FI (Breaking)	−16.57	13.82	−36.49	31.88	42	5
BLD FI (Propulsion)	−30.57	4.42	−36.39	−14.95	46	1
BLD FI (Total positive)	−27.13	3.35	−33.49	−21.23	46	1

BLD, bilateral deficit; BLF, bilateral facilitation; FI, force impulse.

Association Between the Bilateral Deficit and Performance Outcomes

The correlations among BLD variables and performance outcomes can be found in **Table 3**. The approach JH was in moderate negative correlation with BLD in CMJ height ($r = -0.39$; $p = 0.004$). The negative correlation means that the subjects with more BLD (negative number) exhibited higher JHs. Modified *T*-test performance was not correlated with any of the BLD variables ($r = -0.15$–0.22).

Times to perform the 505 test were in small to moderate positive correlation with BLD for CMJ height ($r = 0.36$–0.44; $p = 0.003$–0.014), peak CMJ power ($r = 0.41$–0.47; $p = 0.007$–0.015), and CMJ propulsion phase FI ($r = 0.39$; $p = 0.011$–0.012). The direction of these correlations also implied that 505 performances improved (i.e., lower times) with higher BLD. On the contrary, a statistically significant negative and small correlation between 505 times for the left leg and BLD for braking phase FI was also present ($r = -0.37$; $p = 0.017$), suggesting that lower BLD in this metric is associated with better 505 test performance. There was a negative moderate correlation between CoD deficit for left leg and BLD in PP ($r = 0.42$; $p = 0.007$), indicating that participants with less BLD had a lower CoD deficit.

The BLD in JH was in small correlation with 10 m sprint time ($r = 0.33$; $p = 0.032$) and 15 m sprint time ($r = 0.36$; $p = 0.018$), as well as in moderate positive correlation with 25 m sprint time ($r = 0.49$; $p = 0.001$). In addition, BLD for propulsion phase FI was in moderate positive correlation with 25 m sprint time ($r = 0.42$; $p = 0.007$). For all correlations related to sprinting, the direction of the coefficient suggests superior performance in players with larger BLD.

DISCUSSION

The purpose of this study was to investigate the relationship between BLD in CMJ variables and CoD performance (*T*-test and 505 test), CoD deficit, linear sprinting ability, and approach jump performance on a sample of young male volleyball players. The BLD calculated from CMJ height was smaller (mean: −5.24%) compared with BLD in peak CMJ power (mean: −19.46%) and phase-specific FI variables (means: −16.57 to 30.57%). We found that a larger BLD was associated with better performance in linear sprint and approach jump, which was in accordance with our hypothesis. Results for CoD performance were mixed (no association with modified *T*-test and both positive and negative correlations with 505 test and CoD deficit). The BLD derived from the braking phase FI did not show the relationship with performance or showed smaller relationships than BLD calculated from JH. Thus, we rejected our second hypothesis. Although eccentric strength is of paramount importance for sport performance, especially for CoD tasks (Chaabene et al., 2018), this result could be explained by the fact that the CMJ height is a more holistic measure of neuromuscular ability and reflects different types of strength. While CoD tasks are highly dependent on eccentric strength, the evidence has shown that measures of eccentric, concentric, and isometric strength all contribute to CoD performance (Spiteri et al., 2014).

Previous studies have found either no association (Ascenzi et al., 2020; Nicholson and Masini, 2021) or a small to moderate association between BLD in CMJ and CoD performance (Bishop et al., 2019; Kozinc and Šarabon, 2021). The differences among the studies could be partially attributed to different choices of tests, different populations, and sample sizes. Moreover, when interpreting the relationships between BLD and CoD performance, it is important to consider that traditional CoD tests, such as the 505 test (Nimphius et al., 2016), the *T*-test (Križaj, 2020), and the modified *T*-test (Sassi et al., 2009), are correlated with linear sprinting ability. Therefore, it could be that the relationship between BLD and CoD performance was confounded by the relationship between BLD and linear speed ability. The results by Bishop et al. (2019) suggest that higher BLD is not only associated with superior CoD task performance but also with CoD deficit, which is a more isolated measure of CoD ability

TABLE 3 | Correlations among BLD and performance measures.

Bilateral deficit outcomes	Performance outcomes									
	Approach jump	*T*-test	505 left	505 right	CODD left	CODD right	5 m sprint	10 m sprint	15 m sprint	25 m sprint
BLD jump height	−0.44**	0.22	0.44**	0.36*	0.19	0.18	0.18	0.33*	0.36*	0.49**
BLD peak power	−0.10	0.19	0.41**	0.47**	−0.42**	−0.23	−0.03	0.05	0.11	0.18
BLD FI (Breaking)	−0.05	−0.15	−0.37*	−0.20	0.22	0.21	0.13	0.13	−0.01	−0.15
BLD FI (Propulsion)	−0.30	0.20	0.39*	0.39*	−0.15	0.01	0.00	0.19	0.27	0.42**
BLD FI (Total positive)	−0.12	−0.04	−0.14	0.04	0.19	0.18	−0.05	0.04	−0.01	−0.03

*FI, force impulse; BLD, bilateral deficit; CODD, change-of-direction deficit; *p < 0.05; **p < 0.01.*

(Nimphius et al., 2016). In contrast, Ascenzi et al. (2020) reported no such associations. Our results indicated that higher BLD is associated with superior linear sprinting ability, with the correlations increasing with sprint distance. Given that correlations were very small for the first 10 m of a sprint (r = 0.18–0.33), it is more likely that the influence of BLD is, in fact, associated with CoD performance, with no or less confounding effect of linear sprint ability. This assumption is well supported by Bishop et al. (2019) who found correlations between BLD and 505 times and between BLD and CoD deficit. The fact that two statistically significant correlations were found in this study, which suggests the opposite relationship between CoD performance and BLD (i.e., larger BLD being detrimental to CoD performance), could be explained by the poor reliability of the CoD task outcomes. These correlations were found for the 505 time and the CoD deficit for the left turn, which was far less reliable (ICC = 0.67–0.68; CV = 4.56–15.5%), compared with the right turn (ICC = 0.78–0.87; CV = 3.39–9.68%). In contrast, it has to be considered that the differences between populations have also contributed to the differences between the studies. Future studies investigating the relationship between BLD and CoD performance on different populations are needed to further clarify this aspect.

We found that larger BLD in CMJ height (3 statistically significant correlations) and FI in the propulsive phase (1 statistically significant correlation) are related to better sprint performance. This is in contrast to previous studies that reported no association between BLD and sprinting performance (Bishop et al., 2019; Ascenzi et al., 2020). However, the directions of the correlation coefficients in a study by Bishop et al. (2019) were the same as in this study, and despite not reaching statistical significance, some coefficients were at least moderate (e.g., r = −0.43 for correlation between BLD and 30 m sprint times). The study by Ascenzi et al. (2020) only reported statistical significance without correlation coefficients, making it difficult to compare their results with other studies. In another study, sprinters with a higher BLD were found to produce lower rear leg forces and lower total FI, implying that the BLD should be minimized to optimize sprint start (Bračič et al., 2010). However, given that no performance metric was reported, their study should be interpreted with caution. For now, it could be concluded that BLD in the CMJ may be related to superior linear sprinting, particularly at longer distances; however, the effect is likely small to moderate.

A novel finding of this study was that BLD in CMJ is possibly associated with approach JH. This result is somewhat expected, as the approach jump is performed unilaterally. It has been argued that the BLD should not be necessarily viewed as the deficit, but as "unilateral facilitation" (Škarabot et al., 2016), which can be increased with unilateral training (Häkkinen et al., 1996; Botton et al., 2016). Given the importance of the approach jump task in sports such as volleyball (Forthomme et al., 2005) and basketball, the BLD could be a useful metric to make training-related decisions (e.g., the number of unilateral exercises to be included in the training program). Previous intervention studies comparing the effects of unilateral and bilateral training on strength, power, and speed qualities have reported either no differences between the approaches, or some favorable effects of unilateral training (McCurdy et al., 2005; Botton et al., 2016; Speirs et al., 2016; Gonzalo-Skok et al., 2017; Núñez et al., 2018). It could be that participants with lower BLD (or even bilateral facilitation) are responding faster to unilateral training. Additional research is needed to examine whether lower BLD represents a "window of opportunity" for larger relative improvements in athletic performance in individual athletes. Another consideration for future studies is to incorporate the assessment of the force-velocity relationship when investigating the association between BLD and performance. Namely, the BLD in vertical jumping is largely dependent on the force-velocity relationship of an individual (Bobbert et al., 2006). The force-velocity relationship has been shown to be related to performance, for instance, with spike and serve ball speed in volleyball (Baena-Raya et al., 2021). It could be that the magnitude of the BLD reflects force and velocity capabilities, which are in turn related to performance.

Some limitations and considerations for future research need to be acknowledged and discussed. This study was conducted on male volleyball players, which means that the results should not be generalized to other athletic populations. Moreover, the reliability of the 505 test and the CoD deficit for the left side was unacceptable, which makes the interpretations of these two outcomes difficult. Although the participants were familiar with all testing procedures, additional familiarization sessions could have improved the reliability of CoD outcomes. In addition, although a fair amount of breaks was provided between tasks and repetitions, the overall experimental protocols were relatively demanding, thus, some effects of fatigue cannot be excluded. Finally, although BLD seems to be associated with the performance of volleyball players, it remains to be explored if it is also related to the performance of other sport-specific tasks, such as passing, serving, setting, spiking, blocking, and digging.

CONCLUSION

This study found that larger a BLD, calculated from CMJ variables, is associated with superior linear sprint and approach jump performance. Therefore, BLD might be useful as a tool to assist practitioners in decision-making in athletic training. We suggest that a higher amount of unilateral exercises is prescribed for individuals with lower BLD. We recommend using the CMJ height for the calculation of the BLD, as the BLD obtained from the reaming variables showed smaller or no correlation with performance outcomes.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Republic of Slovenia National Medical Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JP, ŽK, and NŠ conceptualized the idea. JP and ŽK carried out the measurements and analyzed the data collection. NŠ and ŽK were overviewing the measurement procedures and administration and finalized the manuscript. JP wrote the manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

This study was supported by the Slovenian Research Agency through the project TELASI-PREVENT [L5-1845] (Body asymmetries as a risk factor in musculoskeletal injury development: studying etiological mechanisms and designing corrective interventions for primary and tertiary preventive care). University of Primorska also supported the authors through internal research program KINSPO (2990–1-2/2021). The funders played no role in the conceptualization of the study, data acquisition, manuscript writing, or any other phase of the study.

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Conflict of Interest: NŠ was employed by company S2P, Science to Practice, Ltd.

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