Title: The efficacy of a multimodal recovery strategy implemented after a high-intensity rugby league training session

Running Head: Recovery strategies in rugby league

ABSTRACT

The efficacy of a multimodal recovery strategy implemented within 4 h of rugby league (RL) training was investigated using repeated measures randomized cross-over methods in ten professional academy RL players (age: 17 ± 1 years). Following standardized training (5383 m covered, 350 m high-speed running, 28 repeated high-intensity efforts, 24 collisions), players completed a multimodal recovery strategy (i.e., ~640 kcal meal + ~1285 kcal snacks/drinks, cold-water immersion, sleep hygiene recommendations) or control (i.e., ~640 kcal meal: CONT) practices. Isometric mid-thigh pulls (IMTP), countermovement jumps (CMJ) and wellness questionnaires were completed pre- (-3 h) and post-training (+24, +48 h). The recovery strategy influenced IMTP peak force ($p = 0.026$), but between-trial differences were undetectable. No other between-trial effects (all $p>0.05$) were seen for IMTP, CMJ or wellness variables. Training-induced reductions in CMJ peak power (-4 ± 6% vs baseline: 4878 ± 642 W) at +24 h ($p = 0.016$) dissipated by +48 h. Fatigue and lower-body soreness reduced by 16 ± 19% ($p = 0.01$) and 32 ± 44% ($p = 0.024$) at +48 h versus +24 h, respectively. Relative to CONT (i.e., post-training nutrition), the effects of a single bout of recovery practices appeared limited when implemented after-RL-specific training. Therefore, when training included limited collisions, balanced post-exercise meals appeared equally effective relative to a multimodal recovery strategy. Transient changes in performance and wellness variables post-training may have implications for practitioners. Consecutive training sessions, including a high frequency and intensity of eccentric muscle actions should be carefully planned, especially near match-play.

KEY WORDS: Monitoring, neuromuscular, wellness, team sport, intervention

INTRODUCTION

Rugby league (RL) is an intermittent team sport combining high-intensity activities (i.e., high-speed running ≥5.5 $m \cdot s^{-1}$, sprinting ≥7.0 $m \cdot s^{-1}$, accelerations and decelerations) with impacts (i.e., collisions, wrestling and grappling) and low-intensity actions (i.e., standing, walking and jogging) (25, 42, 44). Due to the number and nature of the impacts and the intensity and frequency of eccentric muscle actions that are associated with high-intensity activities, match-play is likely to cause post-match perturbations in neuromuscular (2, 22, 30), biochemical or endocrine (34, 41), or perceptual responses (2, 28). Acknowledging the largely individual nature of recovery time-courses, these responses typically require between 48-72 h to facilitate restoration back to baseline values (1), with nutrition, hydration and sleep being recognized as modulating factors contributing to post-match recovery (15, 16).

To enhance readiness to train or play, it is common for athletes to implement a number of post-exercise recovery strategies (i.e., up to 72 h following match-play) (29, 34, 41). It is well-established that planned nutritional and hydration protocols following exercise can facilitate replenishment of glycogen stores, acceleration of muscle-damage repair and enhanced rehydration (36). Notably, ingestion of 1-1.5 $g \cdot kg^{-1} \cdot h^{-1}$ of carbohydrates (CHO) has been shown to benefit maximal glycogen re-synthesis in the first 4 h following exercise (7), whilst adding 0.2-0.5 $g \cdot kg^{-1} \cdot h^{-1}$ of protein has aided glycogen re-synthesis and enhanced muscle tissue repair, when CHO intake was sub-optimal (i.e., ≤1.2 $g \cdot kg^{-1} \cdot h^{-1}$ (21)). The recuperative effects of sleep have also been suggested to benefit recovery as a result of a restorative relationship with the immune, endocrine and nervous systems (15), with general recommendations supporting 7-9 h of sleep per night (16). Implementing cold-water immersion (CWI) has elicited contrasting findings with some authors observing no benefits following exercise (19, 27), whereas others disagree (12, 35).

While the effects of various recovery modalities have been widely researched within rugby players (40), study designs often include interventions in isolation (i.e., a single strategy implemented on its own) (8, 10, 12, 35, 39). Acknowledging that such an approach may allow for greater experimental control, the limited ecological validity of such studies relative to applied practices may compromise the generalizability of findings in real-world scenarios (for a review see (1)). Notably, a more holistic approach, including multiple recovery strategies, enhanced psychophysiological post-match responses (27). Furthermore, methodological differences persist when assessing the effects of recovery strategies following rugby-specific exercise, with some studies implementing strategies following training (10, 12, 35), simulated matches (4, 19) or actual match-play (13, 33, 39). It is therefore possible that the variability in the context and nature of the preceding exercise bout, especially in relation to the collision aspect, can influence recovery (20).

Implementing recovery strategies is common practice for full-time professional RL players. However, academy RL players (i.e., those in later stages of adolescence; 16-19 years old) who are employed by the club on a part-time basis and have commitments elsewhere (i.e., school, college or work) (2), are limited by employment law in the amount of time spent performing club-related activities. Accordingly, coaching staff may choose to prioritize other activities (e.g., field- or gym-based training, video (p)review sessions) over implementation of recovery strategies as they are perceived to be of greater benefit (3). Indeed, when prioritized against other activities and when contact time with players is already limited, recovery-related activities may not be perceived as worthwhile. Instead, players may be afforded some time off during the immediate days following match-play, after which they return to the club for training in preparation for the following match (3).

Whilst performing recovery modalities on the days following match-play may not always be practical in academy rugby, the initial post-exercise period may pose a realistic alternative for academy players to still benefit from acute implementation of recovery strategies under supervision of the coaching staff. A post-exercise protocol aiming to enhance different elements of recovery (i.e., nutrition, hydration, sleep) in addition to a bout of CWI may be beneficial for player recovery. Therefore, this study investigated the efficacy of a multimodal recovery strategy, implemented within 4 h of high-intensity training, on post-training recovery responses in academy RL players.

METHODS

Experimental Approach to the Problem

Players took part in two standardized field-based training sessions which occurred seven days apart. The initial training session took place approximately ten days after the 2019 academy season finished (i.e., September); a period in which players were exposed to gym-based resistance training to enhance physical capabilities in preparation for the upcoming season. A counterbalanced repeated measures design was used whereby players were randomly assigned to undertake control (CONT) or recovery (REC) interventions during the first week; an order which was reversed in the second week. Players attended baseline testing (subjective wellness questionnaire, isometric mid-thigh pulls; IMTP, countermovement jumps; CMJ) 3 h before each training session and follow-up assessments were performed at +24 and +48 h. Trial interventions (i.e., REC, CONT) were implemented after training.

Subjects

Following institutional ethical approval, 10 male RL players (age: 17 ± 1 years, body mass: 92 ± 10 kg, stature: 1.83 ± 0.06 m) from the same Super League academy (representing the highest tier of academy RL in England) volunteered to take part in this study. Prior to participation, players were provided with full details of the study procedures and were informed regarding the risks and benefits involved with the study. Upon agreeing to participate in the study, players then provided written informed consent before data collection began. All players were declared fit to train by the club's medical staff and completed both training sessions as well as all six assessments before and after the training sessions.

Procedures

Upon arrival for testing, players first completed the wellness questionnaire, followed by a standard dynamic warm-up (including various dynamic movements such as jogging, high knees, heel flicks, lunges, sweeps, and side shuffles). Players then performed two submaximal attempts of the IMTP and CMJ, before commencing the testing protocol. Throughout the study duration, players continued to participate in regular lifestyle commitments (i.e., college, school, work) and were encouraged to maintain their normal dietary intake outside of the interventions. In the week prior to the study commencing, players completed a 'standard' sleep and diet diary as well as a sleep hygiene questionnaire (26), representing their 'regular' sleep and diet routines. Players were encouraged to adhere to these routines when exposed to CONT. Throughout the full duration of the study, players reported their diet for a total of six days whilst a sleep diary and the sleep hygiene questionnaire were completed for each of the four nights during the study.

Subjective Wellness

Players completed a modified wellness questionnaire adapted from McLean et al. (28), which they were accustomed to following its completion in various habituation trials. This questionnaire required a rating of perceived fatigue, sleep quality, upper- and lower-body soreness, stress levels and mood on a 100-point Likert scale, where higher scores represent less fatigue, soreness, stress and better sleep quality and mood. The aggregate sum of all six scores also provided a total wellness score. When recorded on a five-point Likert scale (28, 38), the reliability of such assessments have been questioned (2), especially in academy RL players where acceptable between-day reliability was only achieved in the total wellness score and not by its individual components (2), hence the inclusion of an adapted scale with greater resolution.

Isometric Mid-Thigh Pull

To prepare for testing and to identify the correct pulling position (i.e., knee and hip angle of 120°-135° and 140°-150°, respectively) for each individual (5), players took part in three habituation trials in the week prior to the study commencing. The identified position, replicating the second pull of the power clean, was then repeated between trials. Players were asked to take the required position on the force plate (type: FP4060-05-PT, dimensions: 600 mm x 400 mm, sampling: 1000 Hz, Bertec Corporation, Columbus, OH, USA) and to 'strap themselves' to the bar using lifting straps (XXR Sports, Mitcham, UK) (5). Following goniometry (66fit, Spalding, UK) of both hip- and knee-angles to ensure the correct pulling position, players were instructed to take the slack out of the bar and to 'push their feet into the floor' whilst 'pulling as hard and fast as possible' (14). Once the player and force trace were stabilized, a maximal effort of the IMTP was performed. Players were asked to perform three valid attempts. Efforts were deemed invalid in the case of an unstable weighing period (i.e., large fluctuation in force-time data), if players 'dipped' (i.e., <50 N) or application of prior tension (i.e., >50 N over body weight) before commencement of the pull, or if peak force (PF) occurred at the end of the trial. A large change in body position, or between-trial differences of >250 N also required an additional attempt (2, 9). Raw vertical force-time data were exported into a Microsoft Excel file (Version 2019, Microsoft Corporation), which was later analyzed. The onset of the pull was identified as the point at which force deviated by five standard deviations (SD's) of bodyweight (measured during one second of quiet standing) (9). The IMTP attempt during which PF was achieved, was used for analysis (2). Acknowledging the different variables of the IMTP that may be used to assess neuromuscular function, in academy RL players, acceptable between-day reliability (i.e., coefficient of variation; CV ≤10%, intraclass correlation coefficient; ICC ≥0.8) was previously found in force at 200 (F200) and 250 ms (F250) and PF (2), and were therefore used in the current study

Countermovement Jump

Due to being part of their regular training regimes, players were already familiar with the CMJ. Players were instructed to take place on the force plate with their feet shoulder-width apart and hands akimbo. Following the instruction to 'jump as high and fast as possible', players dipped to a depth of their preference, followed by a jump for maximal height (31). If hands were taken off the hips or knees were tucked in at any point during the jump, the attempt was classified as invalid. Players performed three valid attempts, after which raw vertical force-time data were exported into a Microsoft Excel file. The start of the jump was identified as the point at which force decreased by five SD's of bodyweight (measured during one second of quiet standing) (43). Take-off and touchdown were identified as the times at which force deviated by five SD's during 300 ms of the flight-phase (i.e., when the force plate is unloaded) (32). The jump during which maximal jump-height (JH) was achieved, was used for analysis (2). Whilst a plethora of variables in the CMJ may provide an indication of neuromuscular status, certain variables (i.e., flight-time; FT, PF, (relative) peak power; PP, velocity at take-off; VTO and JH) displayed acceptable levels of between-day reliability in academy RL players (2), and were therefore selected for the current study.

Training Session Design

Training replicated a regular in-season session whereby players performed an athletic warm-up, a skill-based warm-up, team skills and several conditioning games (Figure 1). Both sessions followed the same session plan to replicate locomotive activity profiles as best as possible between trials. Players were also exposed to a block of repeated high-intensity efforts (RHIE) at the end of each training session (23). These bouts of RHIE, previously used as part of a stimulus in fatigue-related research (23), consisted of six efforts performed within one minute with a 1:1 work-to-rest ratio (i.e., each effort was performed in 5 s). Players rested for 30 s following a single bout and performed eight bouts in total. Each bout involved different combinations of collisions and/or running efforts. Collisions involved a hit on each shoulder, utilizing over- and under-hook grips (i.e., pummelling) whilst the running included a 20 m sprint. The combinations of RHIE were either all collisions, all running, mainly collisions (i.e., four collisions and two 20 m sprints) or mainly running (i.e., four 20 m sprints and two collisions). Each combination was used twice in a randomized order to ensure comparability between both sessions (23).

***** INSERT FIGURE 1 NEAR HERE *****

Training Activity Profiles

Locomotive activity profiles of the training sessions were measured using portable micro-electro-mechanical system (MEMS) units sampling at 10 Hz (Optimeye S5, Catapult Innovations, Melbourne, Australia). Players wore these units in a pouch of a vest positioned between the shoulder blades. Units were turned on just before the warm-up and switched off after the training session. Using proprietary software (Openfield Version 2.3.3., Catapult Innovations), data were then downloaded and trimmed to ensure only data pertaining to time spent performing drills was exported for analysis (i.e., any breaks in training were excluded). Alongside total distance and high-speed running (≥5.5 $m \cdot s^{-1}$), the additional external load measures of PlayerLoad and RHIE were analyzed. PlayerLoad describes an accumulation of the tri-axial accelerometers (i.e., anterior-posterior, medial-lateral, and vertical), sampling at 100 Hz, and measures accelerometer-derived activities such as accelerations, decelerations, collisions, jumps, and changes of direction. A RHIE was detected when three or more high-intensity efforts (i.e., high acceleration, high speed running, or collisions) take place with less than 21 seconds between each effort. In addition, subjective internal training load was obtained by a session rating of perceived exertion (sRPE) on a scale from 6 (i.e., no exertion) to 20 (i.e., maximal exertion) (6).

Interventions

In REC, players ingested a balanced post-training meal containing ~640 kcal and additional snacks and drinks containing ~1285 kcal, implemented 10 min of CWI, and were given recommendations regarding their sleeping times and sleep hygiene. Players could drink additional water and/or sugar-free juice ad libitum. A detailed outline of these strategies is shown in Figure 2. In CONT, which was reflective of 'normal practices' at the club, players received the same meal as those in REC and remained in a passive state, whilst sugar-free water and/or juice was also readily available.

***** INSERT FIGURE 2 NEAR HERE *****

Statistical Analyses

All statistical analyses were carried out using statistical software (SPSS version 21, Chicago, IL, USA). Following initial assessments of normality through the Kolmogorov-Smirnov test, two-way repeated-measures analysis of variance (ANOVA; within-participant factors: trial x time of sample) were used to assess between-trial differences (i.e., REC and CONT) over the three time-points. Mauchly's test of sphericity was consulted, and if found statistically significant ($p \leq 0.05$), the null hypothesis was rejected (i.e., sphericity has been violated), and the Greenhouse-Geisser correction was applied. Where significant p-values were identified for interaction effects, the recovery method was deemed to have influenced the post-training response and between-trial differences were assessed using paired samples t-tests. Significant main effects of time were further investigated using pairwise comparisons with Bonferroni adjustment. Statistical significance was set at ($p \leq 0.05$). Cohen's effect sizes (ES) were also used with classifications set at ES<0.2, 0.2≤ ES <0.5, 0.5≤ ES <0.8 and ES ≥0.8 for trivial, small, moderate and large ES, respectively (11).

RESULTS

Training Activity Profiles

Table 1 displays the activity profiles and internal load of both training sessions. Sessions required an average total distance of 5383 ± 410 m, of which 350 ± 85 m high-speed running, with a total number of 28 ± 6 RHIE. PlayerLoad and sRPE values were 596 ± 50 and 15 ± 2 units, respectively. No significant between-session differences existed (Table 1).

***** INSERT TABLE 1 NEAR HERE *****

Isometric Mid-Thigh Pull Response

In the IMTP, trial influenced PF (trial x time interaction: ($F_{(2,18)}$= 4.524, p = 0.026), but no significant between-trial differences were detected through post-hoc testing at any time-point (Figure 3). The recovery protocol had no influence on F200 ($F_{(1,11)}$= 0.649, p = 0.467) or F250 ($F_{(1,11)}$= 0.483, p = 0.545). Training did not influence any of the analyzed variables in the IMTP (i.e., PF, F200, F250). All mean (± SD) responses at baseline, +24 h and +48 h are reported in Table 2. Within-trial time-effects have been displayed via ES in Table 3.

***** INSERT FIGURE 3 NEAR HERE *****

Countermovement Jump Response

In the CMJ, the recovery protocol did not significantly alter any of the variables in comparison to CONT, as FT ($F_{(2,18)}$= 0.723, p = 0.499), PF ($F_{(2,18)}$= 0.540, p = 0.592), PP ($F_{(2,18)}$= 0.264, p = 0.771), relative PP ($F_{(2,18)}$= 0.332, p = 0.722), VTO ($F_{(1,12)}$= 0.007, p = 0.967) and JH ($F_{(2,18)}$= 0.012, p = 0.988) all remained unaffected. The training session influenced PP ($F_{(2,18)}$= 5.223, p = 0.016), as +24 h values were reduced by 4 ± 6% compared to baseline across both REC and CONT (Figure 4). Relative PP was also influenced by training ($F_{(2,18)}$= 4.426, p = 0.027), but post-hoc analyses showed no significant differences between time-points. All mean (± SD) responses at baseline, +24 h and +48 h are reported in Table 2. Within-trial time-effects have been displayed via ES in Table 3.

***** INSERT FIGURE 4 NEAR HERE *****

Wellness Response

Fatigue ($F_{(2,18)}$= 2.673, p = 0.096), sleep quality ($F_{(2,18)}$= 1.320, p = 0.292), upper- ($F_{(2,18)}$= 1.651, p = 0.220) and lower-body ($F_{(2,18)}$= 2.972, p = 0.077) soreness, and total wellness ($F_{(2,18)}$= 1.152, p = 0.338) remained similar between trials over time. As a result of training, fatigue and lower body soreness improved by 16 ± 19% (p = 0.010) and 31 ± 44% (p = 0.024) respectively at +48 h when compared to +24 h values (Figure 5). Total wellness increased by 8 ± 9% (p = 0.008) at +48 h compared to baseline values (Figure 5). All mean (± SD) responses at baseline, +24 h and +48 h are reported in Table 2. Within-trial time-effects have been displayed via ES in Table 3.

***** INSERT FIGURE 5 NEAR HERE *****

***** INSERT TABLES 2 AND 3 NEAR HERE *****

DISCUSSION

This study sought to assess the effect of a multimodal recovery strategy on objective and subjective responses to training that included both high-intensity running and collisions in academy RL players. Although the exercise stress elicited post-training perturbations that persisted for 24 h, the effects of the intervention (i.e., a balanced meal, additional snacks, cold-water immersion, sleep hygiene recommendations) were minimal relative to the control trial (i.e., a balanced meal only) as all but one of between-trial comparisons were similar post-exercise. Therefore, when a post-exercise meal containing ~640 kcal was consumed shortly after training (i.e., 60-90 min), recovery responses were not significantly benefitted further by the addition of the multimodal strategy. As responses in REC were comparable to CONT and acknowledging the likely differences between training and match-play responses, this data supports the consumption of a balanced meal by academy RL players post-training, while highlighting the limited additional benefits of also performing the multimodal recovery strategy following training similar in session-design to that presented here.

Excluding IMTP PF, REC did not significantly influence neuromuscular and perceptual responses over and above those seen in CONT. Due to acute logistical constraints specific to academy RL (i.e., often limited time for recovery methods) (3), the recovery strategy implemented in the present study only focused on the acute post-exercise window (i.e., within 4 h post-training). Nutritional strategies were targeted to shortly after the training session, and although this strategy aligns to post-exercise nutritional recommendations (17, 36), next-day dietary intake was not considered. Likewise, whilst logistically practical, CWI was implemented for a single bout of 10 min, and despite such a strategy having been reported as efficacious previously (27), the accumulated benefits of repeated CWI exposures have also been observed (12, 35). Additionally, sleep hygiene recommendations were implemented on a one-off basis, but in contrast to short-term benefits found previously (8), no sleep-related improvements were demonstrated in the current study. Therefore, even though recovery strategies were implemented in an ecologically valid and time-efficient manner, the efficacy of such an acute intervention following a rugby training session may be questionable when considered against the control condition of a balanced meal only.

Recovery strategies implemented following match-play appear more effective (13, 33, 39) than when preceded by a training session or simulated game (4, 10, 18). Notwithstanding the influence of other confounding variables (e.g., timing, duration and type of recovery strategy used), it is sensible to suggest that the efficacy of recovery interventions are somewhat dependent on the magnitude of muscle damage caused by the preceding stimulus. This may be especially true for the present study, as although training sessions were based around conditioning games which, despite being high in relative distance covered and high-speed running, were relatively limited, though not void of, collisions; especially when considering the number and intensity of collisions compared to match-play. Indeed, Hudson (20) highlighted that significantly increased muscle damage was found following elite rugby union match-play, whilst high-intensity training, albeit eliciting the same physical load (including high-speed running and sprinting metrics), but omitting collisions, resulted in a reduced (i.e., less damaging) response. Speculatively, the collisions encountered on match-day are less controlled and of a higher intensity than those that occur in training, therefore potentially eliciting increased muscle damage, resulting in a more prolonged recovery time-course (20) than observed here. Upper body soreness in the current study remained unaffected, suggesting that physical collisions did not elicit the increased soreness that usually occurs through match-play (24, 38). Indeed, when considered alongside the single application of recovery modalities, together with a dampened (relative to match-play), albeit ecologically valid, training stimulus, it may not be surprising that REC was unable to significantly improve recovery relative to provision of immediate post-exercise nutrition that adhered to authoritative nutritional recovery recommendations (36). However, consuming a balanced meal post-match or post-training may take place at some, but not all, RL clubs, especially when in an academy environment (3). Practitioners are therefore recommended to consider implementing adequate post-exercise nutrition, or, at the very least, provide appropriate education to prime good practice and provide players with appropriate knowledge to make sensible decisions regarding post-exercise nutrition when required to do so by themselves.

Training-induced decrements in PP at +24 h reflected reductions observed post-match-play (29, 30). These responses support the notion that the session did indeed elicit a damaging stimulus given the reduction in selected markers of neuromuscular function observed. From a recovery research perspective, this may offer a surrogate method of eliciting rugby-specific post-exercise perturbations. That said, other analyzed variables of the CMJ (i.e., FT, PF, VTO and JH) remained unchanged, possibly indicating that they were less sensitive to the training stimulus than PP. Differential sensitivity in recovery markers has previously been postulated within the same performance test (2). Notably, increased sensitivity to fatigue has been highlighted in PP relative to those variables primarily assessing force components (i.e., PF) (2, 30), and the findings of the current study support such observations in professional academy RL players. Despite being profiled on a scale allowing for greater resolution of data collected (i.e., 1-100 vs. 1-5), individual components of the wellness questionnaire still require cautious interpretation (2). Nevertheless, despite upper body soreness remaining unchanged, lower body soreness and fatigue were decreased (i.e., less sore/fatigued) at +48 h compared to +24 h, whilst total wellness was increased at +48 h compared to baseline values. These time-effects indicate that high-intensity training sessions may elicit reductions in CMJ PP and subjective responses that last for at least 24 h.

It is well documented that post-match perturbations in neuromuscular, biochemical or endocrine, or perceptual responses may take between 48-72 h to recover (1). During this period, rugby players are unlikely to participate in any high-intensity activity which may prolong their recovery (1). Whilst this is common practice following match-play, the same principle may not apply to training as consecutive training-days are common within academy rugby environments (3). This is despite the fact that the locomotor activity profiles of training sessions (such as those reported here) may at times be similar or greater than the average activity profiles occurring in academy RL match-play (2). Reductions in PP at +24 h, which are comparable to some responses post-match-play (22, 30), indicate that fatigue likely occurred as a result of the prior training session, and player performance may be reduced during this time. Acknowledging that the type and intensity of the training session likely dictates the responses elicited (37), practitioners should be mindful when planning and implementing training sessions on consecutive days. This would be especially true when an accumulation of fatigue may not be the preferred outcome of training (i.e., during the competitive season). Training sessions that are high in frequency and intensity of eccentric muscle actions, and/or in physical impacts are likely to cause perturbations that require at least 24 h to recover. Following such a session, players are encouraged to consume adequate post-exercise nutrition to facilitate the recovery from training. Equally, unless accumulation of fatigue is desired, it may be worthwhile for practitioners to avoid prescribing further high-intensity activity in their players on the following day (i.e., a complete day off or some low-intensity activities which may aid recovery processes). If optimal match performance is sought after, such sessions should not be performed near match-play as players may go into a game in a ‘fatigued’ state.

PRACTICAL APPLICATIONS

When adequate post-exercise nutrition adhering to authoritative nutritional recovery guidelines was implemented following training, additional recovery strategies as used in the present study may not be clearly beneficial, especially if time is restricted to undertake recovery practices. However, it remains unclear whether similar recovery strategies to those used in the current study would benefit players over repeated days of training, when interspersed with the increased demands of match-play.

Practitioners should therefore implement appropriate post-training nutrition, or, at the very least, provide players with education around this subject to prime good practice and allow players to make appropriate decisions when responsible for their own post-exercise nutrition. Although high in relative distance covered and high-speed running, training in the current study included limited physical collisions, especially compared to the amount and intensity observed in match-play. Speculatively, the use of a similar multimodal recovery strategy could be more effective when preceded by a greater exercise stimulus (i.e., match-play). However, this study does offer practitioners a time-efficient and ecologically valid method of implementing various recovery strategies. This may be especially true as academy RL players are often employed by their clubs on a part-time basis and as a result spend a limited amount of time performing club-related activities. Furthermore, the high-intensity training session caused transient changes in performance and wellness variables in the post-exercise period, particularly at +24 h. These findings are notable for practitioners who should be mindful of these effects when planning their weekly training schedule if similar sessions feature in the competitive week, especially if the accumulation of fatigue is not desired. Accordingly, consecutive training sessions focusing on the same musculature that encompass a high frequency and intensity of eccentric muscle actions and include a large amount of high-speed running and RHIE should be carefully considered. Furthermore, to limit the effects of fatigue, such sessions should not be scheduled within 24 h of match-play given the potential for impaired recovery, which may potentially compromise optimal match performance thereafter.

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LEGENDS

Figure 1: Training session design.

Figure 2: Post-training procedures in the recovery (REC) trial. Grey shading denotes recovery procedures undertaken in the control (CONT) trial only.

Figure 3: Mean peak force in the isometric mid-thigh pull before (baseline) and after (+24 h and +48 h) high-intensity rugby league training ($p = 0.026$).

Figure 4: Mean peak power in the countermovement jump before (baseline) and after (+24 h and +48 h) high-intensity rugby league training**.**

Figure 5: Mean fatigue (a), lower body soreness (b) and total wellness (c) before (baseline) and after (+24 h and +48 h) rugby league training.

Table 1: Mean (± standard deviation) training activity profiles and internal load metrics (n=10).

Table 2: Mean (± standard deviation) responses at baseline, +24 h and +48 h in recovery (REC) and control (CONT) trials.

Table 3: Effect sizes (ES) between measures at baseline, +24 h and +48 h in recovery (REC) and control (CONT) trials.

Figure 1

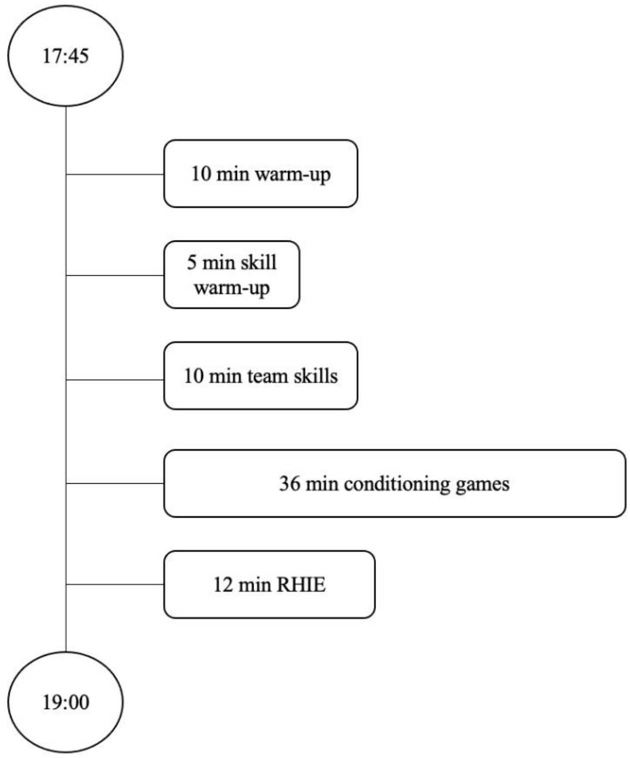

Figure 1. Training session design
RHIE: Repeated high-intensity efforts

Figure 2

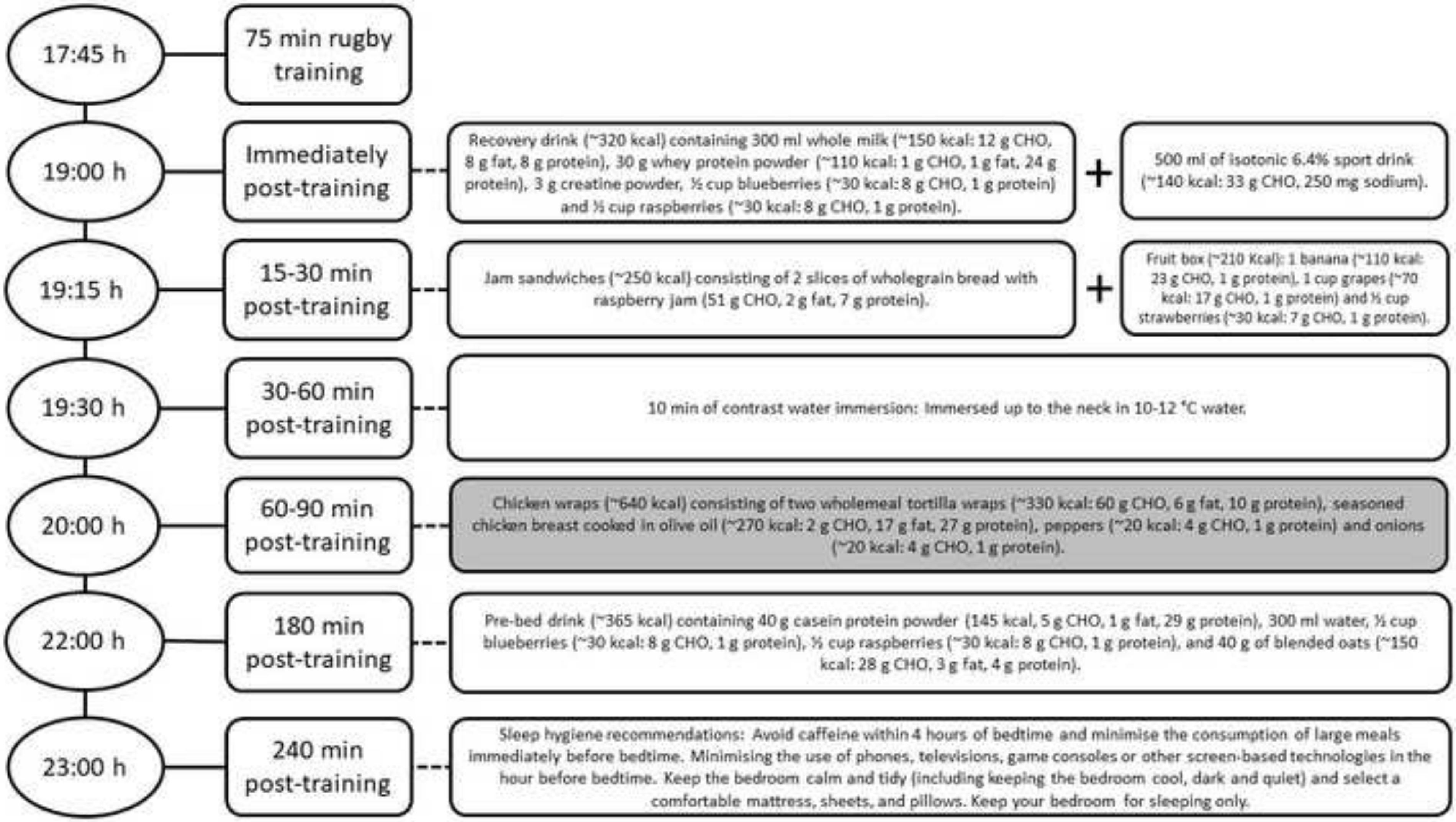
17:45 h
75 min rugby training
19:00 h
Immediately post-training
Recovery drink (~320 kcal) containing 300 ml whole milk (~150 kcal: 12 g CHO, 8 g fat, 8 g protein), 30 g whey protein powder (~110 kcal: 1 g CHO, 1 g fat, 24 g protein), 3 g creatine powder, ½ cup blueberries (~30 kcal: 8 g CHO, 1 g protein) and ½ cup raspberries (~30 kcal: 8 g CHO, 1 g protein).
+
500 ml of isotonic 6.4% sport drink (~140 kcal: 33 g CHO, 250 mg sodium).
19:15 h
15-30 min post-training
Jam sandwiches (~250 kcal) consisting of 2 slices of wholegrain bread with raspberry jam (51 g CHO, 2 g fat, 7 g protein).
+
Fruit box (~210 Kcal): 1 banana (~110 kcal: 23 g CHO, 1 g protein), 1 cup grapes (~70 kcal: 17 g CHO, 1 g protein) and ½ cup strawberries (~30 kcal: 7 g CHO, 1 g protein).
19:30 h
30-60 min post-training
10 min of contrast water immersion: Immersed up to the neck in 10-12 °C water.
20:00 h
60-90 min post-training
Chicken wraps (~640 kcal) consisting of two wholemeal tortilla wraps (~330 kcal: 60 g CHO, 6 g fat, 10 g protein), seasoned chicken breast cooked in olive oil (~270 kcal: 2 g CHO, 17 g fat, 27 g protein), peppers (~20 kcal: 4 g CHO, 1 g protein) and onions (~20 kcal: 4 g CHO, 1 g protein).
22:00 h
180 min post-training
Pre-bed drink (~365 kcal) containing 40 g casein protein powder (145 kcal, 5 g CHO, 1 g fat, 29 g protein), 300 ml water, ½ cup blueberries (~30 kcal: 8 g CHO, 1 g protein), ½ cup raspberries (~30 kcal: 8 g CHO, 1 g protein), and 40 g of blended oats (~150 kcal: 28 g CHO, 3 g fat, 4 g protein).
23:00 h
240 min post-training
Sleep hygiene recommendations: Avoid caffeine within 4 hours of bedtime and minimise the consumption of large meals immediately before bedtime. Minimising the use of phones, televisions, game consoles or other screen-based technologies in the hour before bedtime. Keep the bedroom calm and tidy (including keeping the bedroom cool, dark and quiet) and select a comfortable mattress, sheets, and pillows. Keep your bedroom for sleeping only.

Figure 3

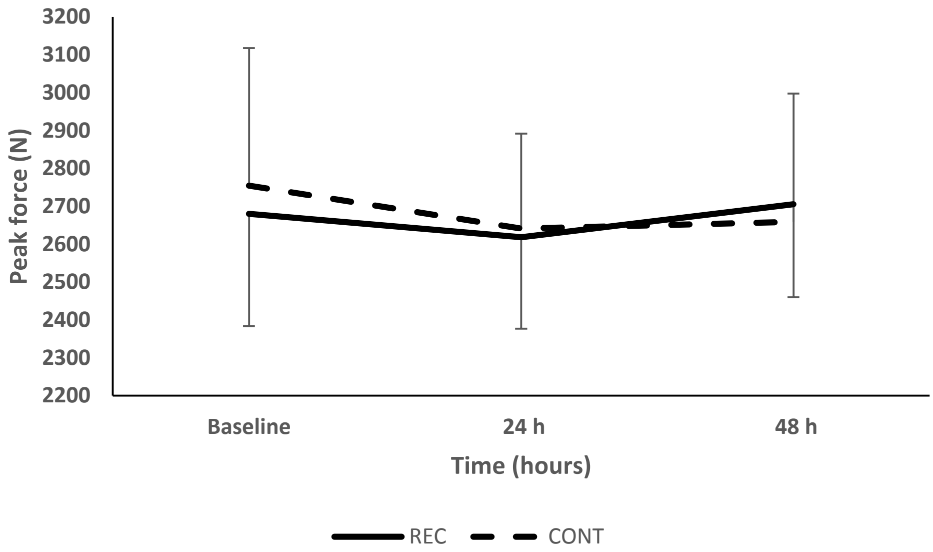

Figure 3. Mean peak force in the isometric mid-thigh pull before (baseline) and after (+24 h and +48 h) high-intensity rugby league training ($p = 0.026$).

Figure 4

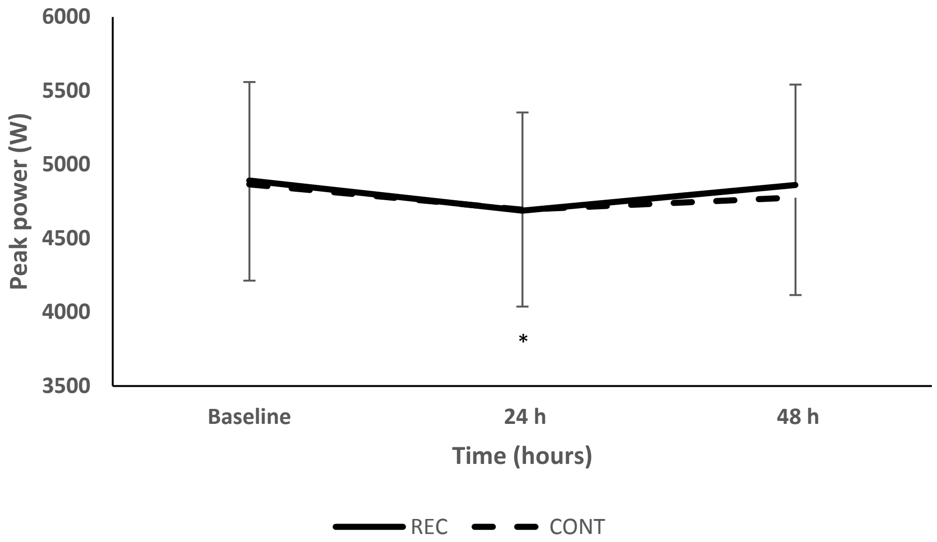

Figure 4. Mean peak power in the countermovement jump before (baseline) and after (+24 h and +48 h) high-intensity rugby league training. * represents significant main effect difference (p≤0.05) to baseline.

Figure 5

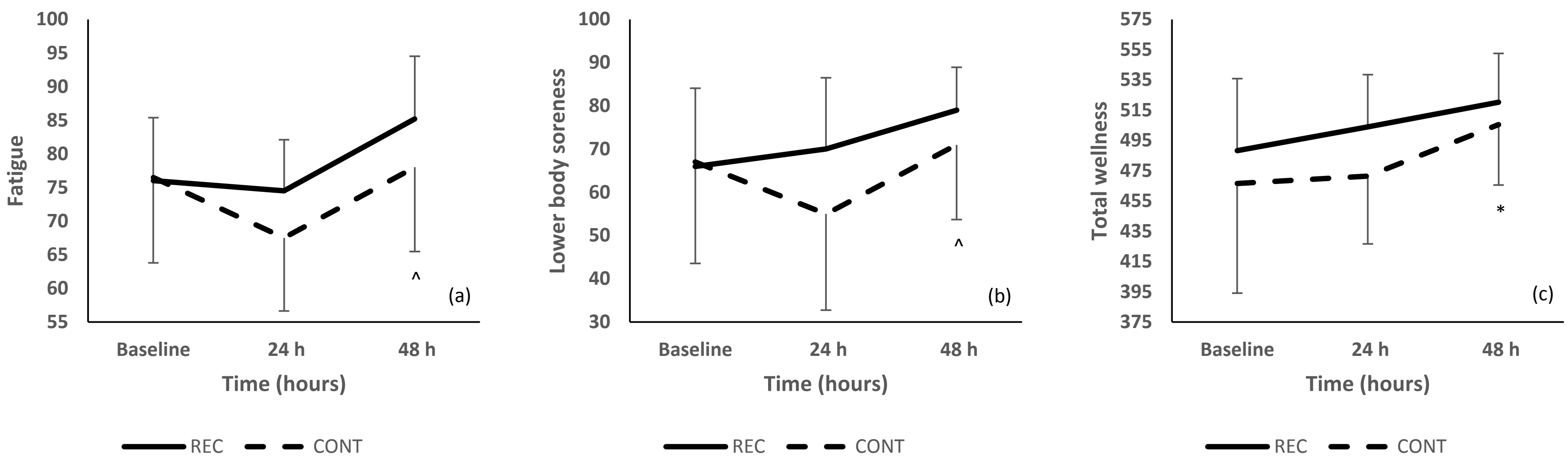

Figure 5. Mean fatigue (a), lower body soreness (b) and total wellness (c) before (baseline) and after (+24 h and +48 h) rugby league training. * represents significant main effect difference (p≤0.05) to baseline. ^ represents significant main effect difference (p≤0.05) to +24 h.

Table 1

Table 1. Mean (± standard deviation) training activity profiles and internal load metrics (n=10)

Timing	Total distance (m)	High-speed (≥ 5.5 $m \cdot s^{-1}$) running (m)	Player load (AU)	Repeated high-intensity efforts (n)	Session rating of perceived exertion (sRPE)
Session 1	5244 (388)	354 (81)	587 (57)	27 (6)	14 (3)
Session 2	5523 (401)	345 (93)	605 (43)	29 (6)	15 (2)

AU: Arbitrary units
The absence of symbols denotes no between-session differences

Table 2

Table 2. Mean (± standard deviation) responses at baseline, +24 h and +48 h in recovery (REC) and control (CONT) trials.

Method	Variable	Trial	Baseline	24 h	48 h
IMTP	PF (N)	REC	2680 (296)	2619 (242)	2706 (245)
		CONT	2755 (363)	2641 (251)	2659 (338)
	F250 (N)	REC	2277 (361)	2275 (307)	2255 (347)
		CONT	2313 (313)	2209 (288)	2256 (393)
	F200 (N)	REC	2168 (369)	2167 (304)	2106 (379)
		CONT	2135 (372)	2042 (316)	2128 (434)
CMJ	FT (s)	REC	0.55 (0.04)	0.55 (0.04)	0.55 (0.03)
		CONT	0.54 (0.04)	0.55 (0.03)	0.55 (0.03)
	PF (N)	REC	2273 (319)	2183 (259)	2264 (281)
		CONT	2244 (245)	2182 (260)	2202 (256)
	PP (W)	REC	4891 (667)	4687 (681)	4860 (616)
		CONT	4865 (653)	4693 (655)	4776 (660)
	Relative PP	REC	55 (4)	52 (4)	54 (4)
	($W \cdot kg^{-1}$BW)	CONT	54 (4)	53 (4)	53 (4)
	VTO ($m \cdot s^{-1}$)	REC	3 (1)	3 (1)	3 (1)
		CONT	3 (1)	3 (1)	3 (1)
	JH (m)	REC	0.36 (0.05)	0.35 (0.04)	0.36 (0.04)
		CONT	0.36 (0.05)	0.35 (0.05)	0.36 (0.04)
Wellness	Fatigue	REC	76 (9)	75 (8)	85 (9)
		CONT	77 (13)	68 (11)	78 (13)
	Sleep Quality	REC	80 (20)	92 (7)	88 (8)
		CONT	81 (16)	86 (15)	87 (12)
	UB Soreness	REC	86 (7)	84 (13)	89 (7)
		CONT	76 (22)	83 (6)	86 (7)
	LB Soreness	REC	66 (18)	70 (17)	79 (10)
		CONT	67 (24)	55 (22)	71 (17)
	Total Wellness	REC	488 (48)	504 (35)	520 (32)
		CONT	467 (72)	472 (45)	506 (40)

BW: Body weight; CMJ: Countermovement jump; CONT: Control trial; F200: Force at 200 ms; F250: Force at 250 ms; FT: Flight-time; IMTP: Isometric mid-thigh pull; JH: Jump-height; LB: Lower body; PF: Peak force; PP: Peak power; REC: Recovery trial; UB: Upper body; VTO: Velocity at take-off.

Table 3

Table 3. Effect sizes (ES) between measures at baseline, +24 and +48 h in recovery (REC) and control (CONT) trials. Moderate (0.5≤ ES <0.8) and large (≥0.8) ES are highlighted in **bold**.

Method	Variable	Trial	Comparison		
			Baseline vs. 24 h (95% CI)	Baseline vs. 48 h (95% CI)	24h vs. 48 h (95% CI)
IMTP	PF	REC	0.23 (-0.66, 1.10)	0.09 (-0.79, 0.97)	0.36 (-0.54, 1.22)
		CONT	0.36 (-0.53, 1.23)	0.27 (-0.62, 1.14)	0.06 (-0.82, 0.94)
	F250	REC	0.00 (-0.88, 0.88)	0.06 (-0.82, 0.94)	0.01 (-0.86, 0.89)
		CONT	0.35 (-0.55, 1.21)	0.16 (-0.72, 1.03)	0.14 (-0.75, 1.01)
	F200	REC	0.00 (-0.87, 0.88)	0.17 (-0.72, 1.04)	0.18 (-0.71, 1.05)
		CONT	0.27 (-0.62, 1.14)	0.02 (-0.86, 0.89)	0.23 (-0.66, 1.10)
CMJ	FT	REC	0.05 (-0.83, 0.92)	0.08 (-0.80, 0.95)	0.14 (-0.74, 1.01)
		CONT	0.19 (-0.69, 1.07)	0.30 (-0.58, 1.18)	0.15 (-0.74, 1.02)
	PF	REC	0.31 (-0.58, 1.18)	0.03 (-0.85, 0.91)	0.30 (-0.59, 1.17)
		CONT	0.24 (-0.65, 1.11)	0.17 (-0.72, 1.04)	0.08 (-0.80, 0.95)
	PP	REC	0.30 (-0.59, 1.17)	0.05 (-0.83, 0.92)	0.27 (-0.62, 1.14)
		CONT	0.26 (-0.63, 1.13)	0.14 (-0.75, 1.01)	0.13 (-0.76, 1.00)
	Relative PP	REC	**0.55** (-0.36, 1.42)	0.13 (-0.76, 1.00)	0.42 (-0.48, 1.29)
		CONT	0.45 (-0.46, 1.32)	0.27 (-0.62, 1.14)	0.17 (-0.71, 1.04)
	VTO	REC	0.20 (-0.69, 1.07)	0.05 (-0.83, 0.92)	0.27 (-0.61, 1.15)
		CONT	0.20 (-0.69, 1.07)	0.08 (-0.80, 0.95)	0.28 (-0.61, 1.15)
	JH	REC	0.21 (-0.68, 1.08)	0.03 (-0.85, 0.91)	0.28 (-0.61, 1.15)
		CONT	0.19 (-0.70, 1.06)	0.07 (-0.81, 0.95)	0.27 (-0.63, 1.13)
Wellness	Fatigue	REC	0.18 (-0.71, 1.05)	**0.98** (0.02, 1.87)	**1.26** (0.25, 2.16)
		CONT	**0.76** (-0.18, 1.63)	0.12 (-0.76, 0.99)	**0.90** (-0.06, 1.77)
	Sleep Quality	REC	**0.80** (-0.14, 1.67)	**0.53** (-0.39, 1.39)	**0.56** (-0.36, 1.43)
		CONT	0.33 (-0.57, 1.20)	0.42 (-0.48, 1.29)	0.07 (-0.81, 0.95)
	UB Soreness	REC	0.19 (-0.70, 1.06)	0.35 (-0.55, 1.21)	0.43 (-0.48, 1.30)
		CONT	0.43 (-0.48, 1.30)	**0.62** (-0.31, 1.49)	0.45 (-0.45, 1.32)
	LB Soreness	REC	0.23 (-0.66, 1.10)	**0.89** (-0.06, 1.77)	**0.66** (-0.27, 1.53)
		CONT	**0.52** (-0.39, 1.39)	0.19 (-0.69, 1.06)	**0.8** (-0.14, 1.68)
	Total Wellness	REC	0.38 (-0.52, 1.25)	**0.79** (-0.15, 1.66)	0.49 (-0.42, 1.35)
		CONT	0.08 (-0.80, 0.96)	**0.67** (-0.26, 1.54)	**0.80** (-0.14, 1.67)

CMJ: Countermovement jump; CONT: Control trial; F200: Force at 200 ms; F250: Force at 250 ms; FT: Flight-time; IMTP: Isometric mid-thigh pull; JH: Jump-height; LB: Lower body; PF: Peak force; PP: Peak power; REC: Recovery trial; UB: Upper body; VTO: Velocity at take-off.