Training sessions with tackles impair upper-limb neuromuscular function in elite rugby union

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ABSTRACT: The aim of this study was to investigate the response to non-tackle and tackle field-based training on upper- and lower-limb neuromuscular function in elite rugby union players. Nine elite senior elite rugby union players (mean age = 21 ± 2 years; height = 184 ± 7 cm; body mass 91.0 ± 9 kg) were evaluated before and immediately following 17 training sessions. A total of 306 assessments were performed. Data on neuromuscular function of plyometric push-up and countermovement jump were calculated from force signals using inverse dynamics. The change from pre- to post-session was investigated across non-tackle and tackle training using a linear mixed model. Considering upper-limb neuromuscular function, peak concentric power [P = 0.024; ES = 0.33 95%CI (0.04, 0.62)] was significantly lower after tackle compared to non-tackle training. In addition, peak countermovement jump eccentric power was significantly lower after non-tackle compared to tackle training [P = 0.044; ES = -0.4 95%CI (-0.69, -0.1)] in lower-limb neuromuscular function. Overall, the results indicated that the type of training influences upper- and lower-limb neuromuscular function differently immediately after training. Indeed, due to physical contact, the upper-body neuromuscular function increased during tackle training. In contrast, lower-body neuromuscular function emerged only in non-tackle training, due to the greater distance covered during this type of training session. Coaches and practitioners should plan adequate weekly training sessions according to this information.

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INTRODUCTION

Rugby union is an invasive field team sport with a high number of collision events. It is characterized by relatively short high-intensity activities (e.g. sprinting, acceleration/deceleration, and change of directions) interspersed with low-intensity activities (e.g., standing, and jogging) over an 80-min period [1, 2]. Depending on their position and competition levels, elite rugby union players typically cover about 5000 to 7000 m during a match (about 60 to 80 m·min^{-1}) [2]. In addition, players are exposed to a significant number of collision events, such as tackling, rucking, and mauling, during both attack and defensive phases [3–5]. As a result, the demanding nature of rugby creates a unique physiological response resulting in short- (i.e., immediately post-match) and long- (i.e. ≥ 24 h post-match) term muscle fatigue [6, 7].

Muscle fatigue can be defined as a transitory, exercise-induced, decrease in the ability to produce force or power [8]. In rugby, the effects of fatigue are evident through the alteration of many physiological functions including a reduction in upper- [9] and lower-limb muscle strength [9–11], increase of fatigue perception [10, 12], mood disturbance [13], and presence of inflammation and markers of damage in skeletal muscle [9, 11]. Therefore, an insufficient recovery following training and competitions, and the consequent fatigue accumulation, may negatively impact athletes' physical performance and, over time, may lead to injury or illness [6, 14].

After a competition, senior and young rugby athletes show an alteration in upper- and lower-limb neuromuscular function. This is usually assessed with dynamic power-based movements such as the plyometric push-up or countermovement jumps [7, 15, 16]. Johnston et al. [9] found reductions in peak force and power during plyometric push-up following an intensified period of competition (i.e., 3 games over a 5-day period). Differently, using the same test Roe et al. [6] observed a decrease in flight time evaluated immediately after a match (about 15%), at 24 h (about 12%), at 48 h (about 4%), and at 72 h (about 1%). Using countermovement jumps, McLellan et al. [17] found that peak rate of force development and peak power decreased for up to 48 hours post-match (about 35 and 30% at 30 minutes post-match and about 27 and 21% at 24 h post-match respectively), while peak force decreased only 30 minutes post-match (about 19%) in elite rugby league players. Lower-limb neuromuscular function reduction was also observed in union rugby players where mean power output immediately decreased by approximately 7% post-match before returning to the pre-match value after 48 h [6, 13].

Furthermore, the evidence of negative correlations between the total number of physical collisions and neuromuscular parameters supports the hypothesis that repeated exposure to high-intensity collisions leads to acute post-match neuromuscular fatigue [11, 12]. Indeed, after a rugby match the total number of collisions and contacts accounted for 36% and 22% of the variance in reductions in peak power [11] and jump height [12]. Interestingly, the higher the severity of the impacts, the longer the time to recover the neuromuscular parameters [11]. Despite this, the competition sessions constitute only a minimal part of time spent on playing rugby. Indeed, during a typical week, players performed several training sessions and generally one competition. For this reason, understanding the players' day-to-day training and the consequent neuromuscular response may be useful to identify appropriate recovery strategies for future competitions [18, 19]. To the best of our knowledge only one study evaluated the effect of collisions (i.e., tackles) in field-based training within rugby union players on fatigue markers [18]. Despite this, the above study simulated a typical training session undertaken at the club and did not observe changes in real-context conditions (i.e., coach's training purposes). Moreover, given the paucity of studies on the impact of tackle and non-tackle training on neuromuscular function in rugby union players, additional studies are needed. Therefore, contrary to the simulated training session scenarios, the present study aimed to investigate upper- and lower-limb neuromuscular function in response to non-tackle and tackle training in elite rugby union players in real-context based training (i.e., coach's training planning and periodization) to improve the application of the results into practice. Based on a previous study [18], we hypothesized finding a different impact of upper- and lower-limb neuromuscular function in response to non-tackle and tackle training. Specifically, we hypothesized that tackle training impaired upper-limb neuromuscular function more while non-tackle training impaired the lower-limb neuromuscular function more.

MATERIALS AND METHODS

Subjects

Due to the real-context condition of this study, no a priori statistical power analysis was calculated and therefore a convenience sample was recruited. Nine elite players including 6 backs (age 21 ± 1 years; height 182 ± 6 cm; body mass 86.0 ± 7.4 kg) and 3 forwards (age 20 ± 2 years; height 188 ± 5 cm; body mass 97.2 ± 6.2 kg) participated in the study. All players were recruited from the same elite Italian *Serie A* team. They had at least 8 years of experience in rugby training and competition and were free from any injury for at least 6 months. Players typically practised 4 times a week (about 120 minutes per session), including resistance training, rugby skills and conditioning, with a competitive match at the end of the week. All the participants provided their written informed consent before participation in the study in accordance with the ethical standards provided in the 1964 Declaration of Helsinki. The study was approved by the Ethical Committee of the University of Torino (Protocol Number: 458273).

Design

A within-group repeated measures design was used to assess upper- and lower-limb neuromuscular function in response to rugby training sessions with or without tackling. Data were collected both before and after 17 (i.e., 11 for non-tackle and 6 for tackle training) field-based training sessions during an in-season period. The tackle training consisted mainly of full-contact tackles and contesting possession within the ruck area. The non-tackle training consisted mainly of blocking tackles, in which the defending player was not interested in bringing to ground the ball carrier and to contest possession within the ruck area. All the training was performed in the evening in the middle of the week, during the in-season period (i.e., from October to December). The total duration of non-tackle and tackle training was 1:59 h ± 16 min and 1:45 h ± 15 min including warming-up. For each training session, players usually performed a 15–20 min warm-up consisting of a light phase (i.e., light jogging, shuffling from side to side, high knees, crossovers, dynamic stretching) and a specific phase (i.e., ball around the hips and around the head, pass games, light tackling and ball carrying contact). Before neuromuscular function assessment (see below), all the participants performed a standardized warm-up consisting of 3 minutes of self-paced cycle ergometry and 2 minutes of dynamic stretching. No intervention was provided to manipulate the contents and planning of training sessions of coach and physical trainer providing real-context experimental circumstances. The typical training routine during the study included technical skills (i.e., passing, kicking, scrumming, tackling, rucking) and tactical drills (attacking, defending, decision making). Thus, the study was conducted in a real-context training situation and these observational data were systematically analysed, without the normal experimental control to keep other factors in check. All measurements were applied on Tuesdays and Wednesdays of in-season weeks, in which the team usually played official matches on Sundays and rested on Mondays.

Procedure

Data on neuromuscular function were collected 15 minutes before and immediately after each training session. External and internal training loads were collected by means of global system positioning devices (GPS) and Edwards' internal training load equation, respectively. Well-being perception was collected 20 minutes before each training session, while data on subjective internal training load were collected within 15–30 minutes from each training session.

Neuromuscular Function Evaluation

Countermovement jumps and plyometric push-up variables were quantified from the ground reaction forces acquired through a piezoelectric portable force platform with charge amplifier (9286AA Kistler, Zurich, Switzerland). The ground reaction forces were sampled at 2048 Hz, converted to digital data with a 16-bit A/D converter (EMG-Quattrocento; OT Bioelettronica, Turin, Italy) and filtered using a low-pass filter with a cutoff frequency of 50 Hz [20].

Before neuromuscular function assessment, participants performed 2 practice trials of submaximal countermovement jumps and plyometric push-ups. After the warm-up, each test was measured with 2 trials, with the rest between trials being around 1 minute. Participants stood still on the force platform for the initial 2 seconds of the data collection period in order to determine body weight [21].

For the countermovement jump test each participant started in standing position on the force platform with knees extended and feet in a position of the participant's choice [22]. While keeping their arms akimbo subjects performed the jumps as quickly and as high as possible [21, 23]. For the plyometric push-up, participants started in the press-up position with their hands in a self-selected position on the force platform with extended arms. Participants were instructed to extend their elbows as quickly as possible so that their hands left the platform [9]. All participants started both the countermovement jump and the plyometric push-up at the experimenter's signal. No instructions on the depth of the countermovement jump and plyometric push-up were given and it was individually determined by each subject [9, 21, 22].

Neuromuscular Function Data Analysis

The centre of mass (COM) velocity was determined by dividing ground reaction force by body mass and then integrating the product using the trapezoid rule while instantaneous COM displacement was obtained by integrating twice the vertical force data [21, 24]. The beginning and the end of the eccentric and the concentric phase were defined as previously suggested [21]. Specifically, the eccentric phase was calculated as the period between negative peak and zero COM velocity. The concentric phase was calculated as the period between the instant when COM velocity exceeded 0.01 $m \cdot s^{-1}$ and the instant of take-off. Take-off and landing were identified when the vertical ground reaction force fell below and exceeded five times the standard deviation of the flight phase force, respectively [21, 23]. Eccentric and concentric peak vertical force and mean vertical force were obtained from the ground reaction force (minus body weight) data. Instantaneous power was calculated by multiplying vertical force and velocity data at each time point. Afterwards, the mean and eccentric and concentric peak power values were calculated. Using the trapezoid rule, eccentric and concentric net impulse was calculated as the area under the net ground reaction force curve (minus body weight). Maximal rate of force development was defined as the eccentric peak vertical force divided by the time to reach this peak value [21]. As previously suggested, height for the countermovement jump test was derived from vertical velocity at take-off while the modified reactive strength index (RSImod) was calculated as height divided by the movement time [23, 25]. No data about height and RSImod were obtained for the plyometric push-up because the whole system mass was not applied to the force plate during the movement. All data were analysed by using custom-written software in MATLAB R2019b (MathWorks, Natick, MA, USA).

Well-being Perception

To assess well-being perception, participants filled in a questionnaire adapted by McLean et al. [10], which assessed their fatigue, sleep quality, general muscle soreness, stress levels and mood on a five-point scale (score range 1 to 5 points). This short questionnaire is usually adopted in rugby research [10, 22, 26] to investigate the specific components generally used to assess training imbalances [27, 28]. Overall well-being perception was determined by summing the five scores, with the total score ranging from 5 to 25. Higher scores indicated a higher level of well-being perception. According to a previous study on rugby players, the between-day reliability of the wellbeing questionnaire had a CV of 7% [22]. The well-being questionnaire was individually administered 20 minutes before the training session.

Objective External Load

Objective internal load was assessed using a global system positioning devices (GPS). Each player wore a GPS unit sampling at 10 Hz (Spin_GNSS_50Hz, Spinitalia S.r.l., Italy) positioned on the upper thoracic spine between the scapulae [15]. All the GPS units were switched on at least 15 minutes prior to the training session to ensure a full high-quality satellite signal and were downloaded and analysed using a customized software (LagalaColli 10.03 Spinitalia SRL, Italy) following each training session. GPS data regarding total distance (TD) were used for the analysis. For distance measurement, a previous study showed good validity and reliability (ICC $\geq$ 0.99) of the GPS unit [29].

Internal Training Load

Internal training load was assessed by means of Edwards' heart rate method, which uses accumulated time (expressed in minutes) in five arbitrary heart rate zones (i.e., 50–60% = 1; 60–70% = 2; 70–80% = 3; 80–90% = 4; 90–100% = 5) multiplied by a weighting factor [30]. Each player wore a heart rate monitor (Team Pod; Firstbeat, Finland) sampling at 1 s intervals which was connected wirelessly with a mobile computer (ASUS Notebook Series; ASUSTek Computer Inc; Taipei, Taiwan). The sum of all 5 intensity zones of Edwards' internal training load was derived from heart rate and was expressed as arbitrary units.

Subjective internal training load (e.g., perceived training load) was assessed using session rating of perceived exertion [sRPE; 31]. Approximately 20–30 minutes after each training session, each player individually provided an RPE about the whole training session using the Italian translation of the modified CR-10 version [32] of Borg's scale. Each value was multiplied by session duration (expressed in minutes) to estimate sRPE.

Statistical Analyses

The difference between non-tackle and tackle training was investigated using linear mixed models with kinetic and kinematic countermovement jump and plyometric push-up parameters (collected separately to the different 17 training sessions) as dependent variables. The Type (i.e., non-tackle and tackle training session) was considered as a fixed effect, with individual athletes' identification included as a random effect within the model. Baseline parameter, sRPE, and total distance entered the model as covariates. Cohen's *d* effect sizes (ES) with 95% were calculated from resultant *t* ratios to describe the practical meaningfulness of the differences in mean values [33]. The absolute ES value was evaluated according to the following thresholds: < 0.2 = trivial, 0.2–0.6 = small, 0.7–1.2 = moderate, 1.3–2.0 = large, and > 2.0 = very large. All the statistical analysis was carried out using the statistical package R (version 3.5.2) with the packages *lme4* (version 1.1.19), *emmeans* (version 1.3.2) and *compute.es* (version 0.2.4).

RESULTS

The total duration of non-tackle and tackle training was 1.59 h ± 16 min and 1.45 h ± 15 min respectively ($P > 0.05$). Significant differences (all P values < 0.05) between non-tackle and tackle training were observed in sRPE (291.59 ± 116.71 AU vs 335.17 ± 126.43 AU) and in total distance (6297 ± 1239 m vs 5004.93 ± 878.51 m). Conversely, no significant differences were observed between non-tackle and tackle training in Edwards' internal training load (200.13 ± 52.35 vs 198.86 ± 42.13 AU) or in well-being perception (16.05 ± 2.75 vs 15.85 ± 1.97 points).

An overview of linear mixed model outputs for kinetic and kinematic plyometric push-up parameters is displayed in Table 1. Figure 1 shows the relative Cohen's *d* ES provided by the generalized linear model.

After adjustment for baseline value, sRPE and total distance a statistically significant difference was observed between the non-tackle and tackle training in peak concentric power [P = 0.024; ES = 0.33; 95% CI (0.04, 0.62)] immediately after the training session. Specifically, peak concentric power was significantly lower after tackle compared to non-tackle training [mean difference = -38.6 W; 95% CI (-71.9, -5.23)]. Conversely, no significant differences were observed in other kinetic and kinematic plyometric push-up parameters, while trivial to small ES were found (for more details see Figure 1).

An overview of linear mixed model outputs for kinetic and kinematic countermovement jump parameters is displayed in Table 2. Figure 2 shows the relative Cohen's *d* ES provided by the generalized linear model.

After adjustment for baseline value, sRPE and total distance, a statistically significant difference was observed in peak eccentric power in post-training between the non-tackle and tackle training [P = 0.044; ES = -0.4; 95% CI (-0.69, -0.10)]. Specifically, peak eccentric power was significantly lower after non-tackle training

TABLE 1. Comparison of kinetic and kinematic plyometric push-up variables between non-tackle and tackle training

Plyometric push-up variables	Non-Contact			Contact			Percentage Difference
	M	SE	95% CI	M	SE	95% CI	
Velocity at Take-off (m·s^{-1})	1.87	0.054	(1.75, 2.00)	1.80	0.059	(1.66, 1.93)	-3.7%
Movement Time (s)	1.01	0.043	(0.91, 1.10)	1.04	0.042	(0.95, 1.14)	3.0%
Eccentric Phase Time (s)	0.481	0.015	(0.446, 0.517)	0.478	0.015	(0.442, 0.514)	-0.6%
Concentric Phase Time (s)	0.196	0.009	(0.173, 0.219)	0.196	0.010	(0.173, 0.219)	0%
Eccentric COM Displacement (m)	0.180	0. 004	(0.169, 0.19)	0.181	0.005	(0.170, 0.191)	0.6%
Concentric COM Displacement (m)	0.790	0.029	(0.722, 0.859)	0.757	0.031	(0.687, 0.827)	-4.2%
Peak Eccentric Force (N)	854	30.8	(782, 926)	868	33.8	(782, 926)	1.6%
Peak Concentric Force (N)	878	23.6	(823, 934)	871	25.8	(814, 928)	-0.8%
Mean Force (N)	291	13.9	(258, 324)	286	14.2	(252,319)	-1.7%
Peak Eccentric Power (W)	531	58.4	(397, 665)	520	60.1	(384, 655)	-2.1%
Peak Concentric Power (W)	626	17.1	(587, 666)	588	19.7	(545, 630)	-6.1%
Mean Power (W)	389	13.2	(357, 422)	374	14.3	(341,406)	-3.9%
Eccentric Impulse (N·s)	82.6	1.96	(78.0, 87.1)	82.3	2.17	(77.5, 87.0)	-0.4%
Concentric Impulse (N·s)	108	3.36	(100.4, 116)	105	3.58	(96.6, 113)	-2.8%
Rate of Force Development (N·s^{-1})	2521	240	(1964, 3077)	2436	247	(1874, 2998)	-3.4%

Note: Relative percent change is the difference between non-tackle and tackle training; M, Mean; SE, Standard error; 95% CI, 95% confidence interval.

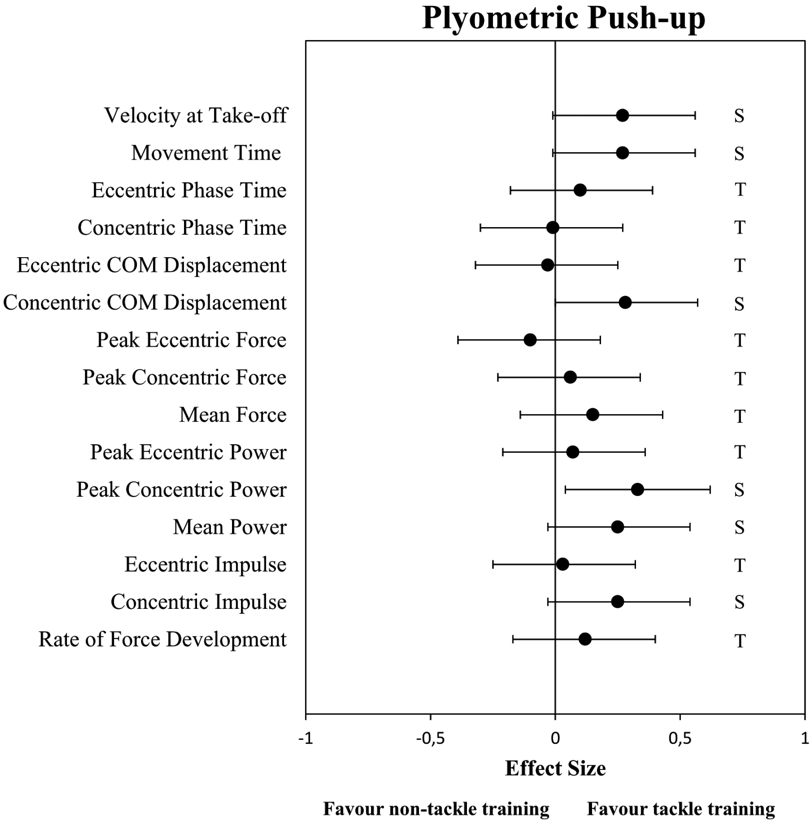

FIG. 1. Forest plots of Cohen's *d* effect size and 95% CI provided by the generalized linear model for plyometric push-up. Effect size magnitude: T, trivial; S, small.

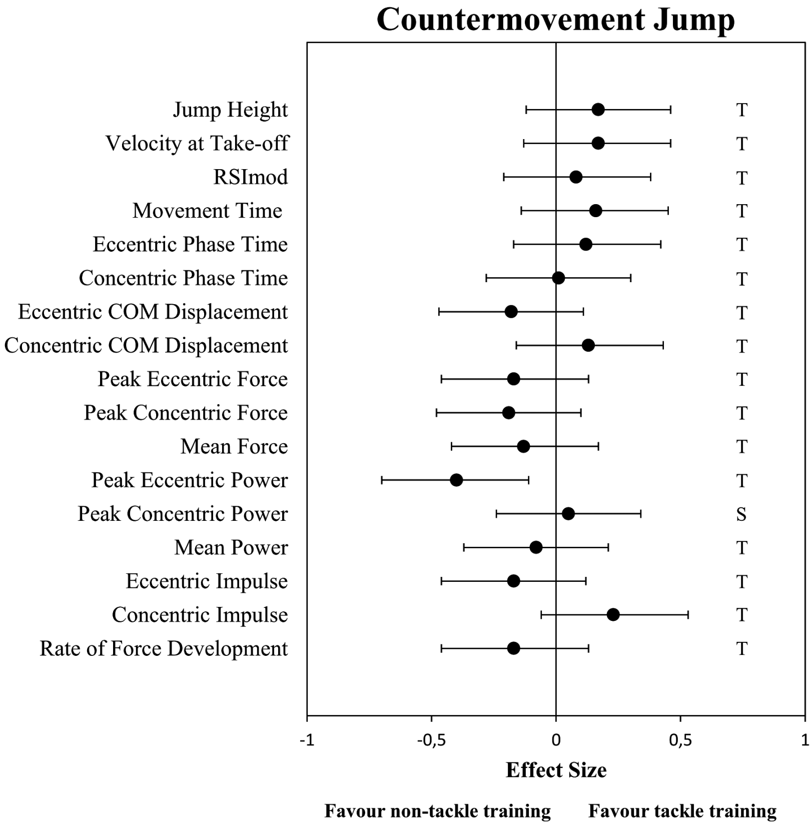

FIG. 2. Forest plots of Cohen's *d* effect size and 95% CI provided by the generalized linear model for countermovement jump. Effect size magnitude: T, trivial; S, small.

Table 2. Comparison of kinetic and kinematic countermovement jump variables between non-tackle and tackle training

Countermovement jump variables	Non-Contact			Contact			Percentage Difference
	M	SE	95% CI	M	SE	95% CI	
Jump Height (m)	0.354	0.005	(0.343, 0.364)	0.345	0.006	(0.332, 0.358)	-2.5%
Velocity at Take-off (m·s^{-1})	2.62	0.014	(2.59, 2.65)	2.59	0.022	(2.55, 2.64)	-0.8%
RSImod	0.491	0.010	(0.470, 0.512)	0.483	0.014	(0.455, 0.510)	-1.6%
Movement Time (s)	0.734	0.008	(0.717, 0.750)	0.719	0.011	(0.697, 0.741)	-2.0%
Eccentric Phase Time (s)	0.249	0.003	(0.242, 0.256)	0.247	0.004	(0.239, 0.254)	-2.8%
Concentric Phase Time (s)	0.151	0.003	(0.145, 0.157)	0.151	0.003	(0.144, 0.158)	0.0%
Eccentric COM Displacement (m)	0.130	0.002	(0.125, 0.134)	0.134	0.003	(0.128, 0.139)	3.1%
Concentric COM Displacement (m)	0.399	0.005	(0.388, 0.410)	0.393	0.007	(0.379, 0.406)	-1.5%
Peak Eccentric Force (N)	1308	38.0	(1218, 1397)	1333	39.9	(1243, 1424)	1.9%
Peak Concentric Force (N)	1335	31.4	(1261, 1410)	1363	33.7	(1287, 1439)	2.1%
Mean Force (N)	884	20.3	(837, 932)	896	21.6	(848, 945)	1.4%
Peak Eccentric Power (W)	858	52.1	(740, 976)	957	56.3	(835, 1079)	11.5%
Peak Concentric Power (W)	2566	55.2	(2423, 2709)	2551	60.8	(2408, 2694)	-0.6%
Mean Power (W)	1112	32.7	(1035, 1190)	1123	34.7	(1044, 1202)	1.0%
Eccentric Impulse (N·s)	120	1.51	(117, 124)	123	1.91	(119, 127)	2.5%
Concentric Impulse (N·s)	232	1.46	(229, 235)	229	1.90	(225, 233)	-1.3%
Rate of Force Development (N·s^{-1})	5443	263	(4848, 6038)	5703	291	(5076, 6331)	-6.7%

Note: Relative percent change is the difference between non-tackle and tackle training; M, Mean; SE, Standard error; 95% CI, 95% confidence interval.

compared to tackle training [mean difference = -46.5 W; 95% CI (0.58, 92.30)]. Conversely, no significant difference was observed in other kinetic and kinematic countermovement jump parameters, while trivial to small ES were found (for more details see Figure 2).

DISCUSSION

The aim of this study was to investigate the response to non-tackle and tackle field-based training on upper- and lower-limb neuromuscular function in elite rugby union players. Overall, the results indicated that the neuromuscular function of upper and lower limbs was not severely impaired after training sessions executed in a real-context training setting. However, the presence or absence of tackles has subtle influences on upper- and lower-limb neuromuscular function, respectively. Indeed, the upper-limb neuromuscular performance was lower after the sessions with tackles. In contrast, a lower-limb neuromuscular function decrease emerged only in non-tackle training, probably due to the greater distance covered during this type of training session. In other words, a heterogeneous amount of total distance or performed tackles differently influences the response of upper- and lower-limb neuromuscular function after a training session.

The inclusion of tackles in the training sessions may induce subtle changes in the neuromuscular function of upper limbs. Indeed, a general decrease in plyometric push-up parameters in tackle compared to non-tackle training immediately after training sessions was observed. These results were in line with previous studies that underlined upper-limb neuromuscular fatigue following tackle training [18, 34] and competitions [6, 9, 35]. We found that the peak concentric power was 6.1% lower after tackle compared to non-tackle training. These differences correspond to small magnitude effects [ES = 0.33; 95%CI (0.04, 0.62); see Figure 1]. In line with the above results, a lower velocity at take-off (-3.7%), concentric COM displacement (-4.2%), mean power (-3.9%) and concentric impulse (-2.8%) was observed in tackle compared to non-tackle sessions (ES range: 0.25–0.28; See Figure 1). Nevertheless, the results did not reach significant differences. Similar results were observed in previous studies evaluating the difference in neuromuscular fatigue following non-tackle and tackle training. For example, Roe et al. [18] observed a greater reduction in plyometric push-up flight time during simulated tackle training compared to non-tackle training in professional rugby union players. In particular, push-up flight time decreased by about 6% and 7% immediately after and 24 h after training in response to a contact session while a smaller increase (about 2% and 3% respectively) was observed in response to a non-contact session [18]. Moreover, a large to moderate reduction in upper-limb peak power and force was observed in junior elite rugby league immediately following small-sided games training with physical contact, at 12 h and 24 h, while no change was observed in game training with non-physical contact [34]. Some interpretations could be provided to more deeply interpret the results of the present study. The decrease in upper-limb neuromuscular function can be attributed to physical contact (i.e., tackling and being tackled and intense static actions such as scrums, rucks and mauls) [11, 12]. Upper limbs are substantially involved in physical collisions both during competition [12] and training sessions [18, 34]. Consequently, the repeated exposure to high-intensity collisions (e.g., tackle) may result in acute tissue damage and soreness [12, 34, 36] presenting due to direct impacts on upper limbs. Interesting, despite there being no difference in Edwards' internal training load between non-tackle and tackle training, we observed that the sRPE outcome was significantly greater for the tackling training. These differences correspond to upper-limb neuromuscular performance decrease.

In contrast, a different pattern was observed in lower-limb neuromuscular function. Indeed, we found countermovement jump lower peak eccentric power (-8.4%) after tackle compared to non-tackle training sessions, corresponding to a small magnitude effects (ES: -0.30; see Figure 2). These results are in line with previous studies that investigated the effect of physical contact during training sessions [18, 34]. It is possible to speculate that the greater locomotive demands in term of total distance during non-tackle (mean distance = 6297 ± 1239 m) rather than tackle training (mean distance = 5004.93 ± 878.51 m) may exacerbate the difference between the two different types of training session. Similarly, Roe et al. [18] found a decrease of about 7% immediately after tackle training, despite the experimental session of that study consisting of simulated tackle training with shorter covered distance (e.g., about 2500 m). From a technical and tactical perspective, decrements in neuromuscular function should be considered along with the playing efficiency. In fact, successful performances in elite northern hemisphere rugby union mainly consist of lower possession, defending more, and carrying the ball less than losing counterparts [37]. Thus, coaches should train players to improve decision making by encouraging them to adopt effective attacking strategies (i.e., side-stepping pattern for the straightening of the running line) as well as to perform effective tackles during defending phases [37].

Several potential limitations should be underlined. The inclusion of a single team and a small sample size did not allow us to generalize our results or to identify possible differences between roles (e.g., backs and forwards). However, we collected data on 11 non-tackle and 6 tackle training sessions, avoiding any intervention on training; thus this aspect should be considered. Moreover, upper- and lower-limb neuromuscular function was only assessed immediately following the training sessions and therefore there is a lack of follow-up at 24 h and 48 h. This limit did not allow the long-term effect of non-tackle and tackle training to be tracked. However, due to the players' training schedule, it was not possible to obtain these data. A further limitation of the study is that we used GPS technology to estimate the objective external load. This type of technology decreases the reliability of data compared to a local positioning system (LPS), which currently represents the most valid and reliable technology for evaluating movement patterns in team sports [38]. For the above reason future research is needed to better understand the relationship between tackle and no-tackle training, especially considering long-term effects (i.e., 24 h and 48 h) in real-context training situations.

CONCLUSIONS

This study monitored typical training sessions in a real-context training situation and provided differences between the effects of non-tackle and tackle training on neuromuscular function. Given the high number of training sessions typically performed by an elite rugby union team during the week, these findings highlight the need to monitor and adequately programme training to avoid the subsequent performance decline in forthcoming training sessions and matches. Since the players' responses are different in relation to tackle and non-tackle training, coaches and practitioners should plan adequate weekly training sessions according to this information. In conclusion, non-tackle and tackle training sessions appear to impact differently upper- and lower-body neuromuscular function in elite rugby union players. The inclusion of tackles during training leads to a greater decrease in upper-body neuromuscular function. In contrast, a decrease in lower-limb neuromuscular function emerged in non-tackle training.

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Conflict of interest declaration

No potential conflict of interest was reported by the authors.

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