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EFFECTS OF RESISTANCE TRAINING ON SELECTION AND PERFORMANCE IN RUGBY UNION PLAYERS

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Summary

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LIST OF PUBLICATIONS

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- Trecroci A., Formenti D., **Duca M.**, Cavaggioni L., D'Angelo F., Passi A., Longo S., Alberti G.,
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ABSTRACT – ITALIANO

Introduzione: Durante una partita, le richieste di gioco per un giocatore di rugby dipendo dalla posizione in cui gioca. Gli avanti sono coinvolti più spesso in fasi statiche (mischie, raggruppamenti a terra e in piedi), mentre i tre quarti devono svolgere più frequentemente azioni dinamiche (sprintare, saltare, cambiare direzione). Sono queste richiese di gioco a determinare le caratteristiche antropometriche e fisiche richieste ad un giocatore per avere successo. Gli avanti sono più pesanti e forti, mentre i tre quarti sono più snelli e veloci. In generale, nonostante la letteratura riporti che giocatori più pesanti e pesanti siano favoriti ad essere selezionati per le competizioni internazionali, le informazioni sono limite per quanto riguarda giocatori italiani. Corporatura, forza, potenza e velocità possono essere efficacemente migliorate con un allenamento con sovraccarichi. Al momento però non vi sono informazioni definitive rispetto a quale sia la metodologia più efficace da impiegare quando si allenano degli atleti. Per esempio, l'efficacia dell'allenamento fino al cedimento muscolare (FAIL), che sembrava essere indispensabile per migliorare ipertrofia e forza muscolare, più recentemente è stata contestata poiché l'allenamento senza cedimento muscolare (NO-FAIL) è stato mostrato garantire superiori miglioramenti nei valori di forza e potenza degli atleti.

Scopo: Lo scopo di questa tesi è duplice. Dapprima individuare quali caratteristiche siano perditrici della selezione per competizioni internazionali in giocatori italiani della categoria U20. In secondo luogo, quale tra FAIL e NO-FAIL, possa maggiormente migliorare le caratteristiche antropometriche e fisiche dei giocatori.

Metodi: Per il primo scopo, è stata svolta un'analisi retrospettiva sulle caratteristiche fisiche e antropometriche, raccolte testando le variabili di 72 giocatori U20. È stata svolta un'analisi della varianza (ANOVA) a due vie, ponendo come fattori tra soggetti la posizione e la selezione per competizioni internazionali. La selezione è stata inoltre posta come variabile dipendente della regressione logistica. Per il secondo scopo, 16 giocatori di rugby amatoriali sono stati assegnati ad uno di due gruppi sperimentali (FAIL o NO-FAIL) e hanno svolto un programma di allenamento contro sovraccarichi della durata di sette settimane. Le variabili antropometriche e fisiche sono state testate prima e dopo il programma sperimentale.

Risultati: ANOVA non ha rilevato nessun effetto significativo per l'interazione. La massa corporea e la forza massimale degli arti inferiori sono risultate perditrici della selezione nei giocatori U20. Analizzando gli effect size, è stato possibile vedere che i giocatori del gruppo NO-FAIL sono migliorati maggiormente nella forza massimale degli arti inferiori, nell'altezza e potenza del salto verticale, nello sprint e nel cambio di direzione.

Conclusioni: corporatura e forza massimale dei giocatori sono fondamentali per la selezione a livello internazionale nel rugby. L'allenamento con sovraccarichi FAIL comporta dei miglioramenti inferiori in queste variabili e quindi dovrebbe essere evitato. I preparatori atletici dovrebbero preferire l'uso di metodologie che consentano una maggior regolazione dell'intensità di allenamento, così da sfruttare i superiori miglioramenti di forza, potenza e velocità.

Parole chiave: forza, potenza, sprint, allenamento con sovraccarichi, rugby

ABSTRACT

Introduction: Rugby union players must cope with diverse match demands depending on the playing position. Forwards (FWS) are more often engaged in static exertions (scrums, rucks, mauls) while backs (BKS) exhibition more dynamic actions (sprints, jumps, change of direction). These match demands dictate the anthropometrical and physical characteristics required to players to be successful. FWS are heavier and stronger, while BKS are leaner and faster. Despite the literature shows an overall advantage for stronger and heavier players to selection for international competition, limited data is present for Italian players. Body size, strength, power, and speed can be effectively improved by resistance training (RT). Yet, the debate is still open on the most effective RT modality for athletes. For instance, the efficacy of training to momentary muscular failure (FAIL), which seemed paramount towards increase muscle hypertrophy and strength, have recently been debated as RT not to failure (NO-FAIL) showed superior improvement in athletes' strength and power.

Aim: The aim of this thesis is two folds. First, which characteristics are predictor of selection for international competitions in Italian U20 players. Secondly, to assess the superior efficacy of either FAIL or NO-FAIL RT programs on improving players' anthropometric and physical characteristics.

Methods: For the first aim, anthropometric and physical characteristics, collected testing the variables of 72 U20 players, were retrospectively analyzed. Two-way analysis of variance, with selection for international tournaments and playing position as between subjects' factors, was completed. Selection was also chosen as the dependent variable of multiple logistic regressions. For the second aim, 16 amateur rugby players were assigned to one of two groups (FAIL or NO-FAIL) and completed a seven weeks long RT program. Players' anthropometric and physical variables were tested before and after the intervention.

Results: ANOVA did not detect any significant interaction effects. The players' body mass and lower body maximal strength resulted predictors of selection for U20 players. Analysis of the effect sizes qualified that NO-FAIL RT allowed for superior improvements in lower body maximal strength and power, vertical jump height and power, linear sprint and change of direction.

Conclusions: players' body size and maximal strength are crucial for international selection in rugby. RT to FAIL elicits inferior improvements in these variables, and it should therefore be avoided. Strength and conditioning coaches should favor methods that allow for a better training intensity management in rugby players and exploit superior improvements in strength, power and speed.

Keywords: strength, power, sprint, strength training, rugby

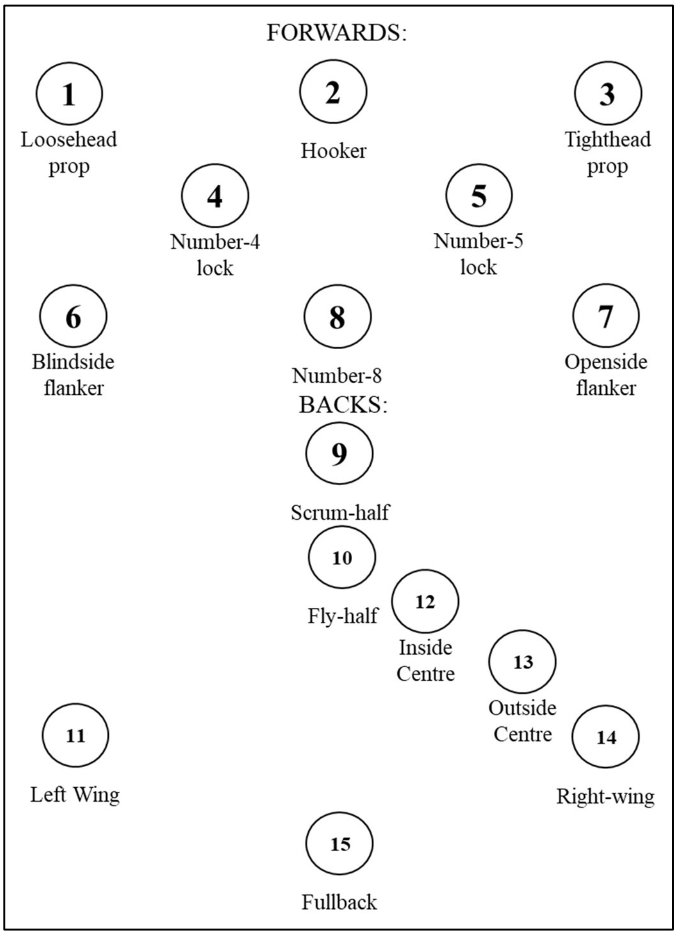
1. INTRODUCTION

Rugby union is a popular sport, played worldwide at both professional or amateur and youth level. The game is characterized, unlikely to other large field invasion sport, by high-intensity actions interspersed by low intensity recovery phases. During the high-intensity actions players must display a wide arrange of physical abilities as they are required to sprint, jump, tackle and fight for the control of the ball. This duality of being both a running and a fighting sport dictates the peculiar physical traits required to players to be successful at national and international level. Players are therefore required to be strong, powerful, fast, and possess adequate endurance to repeat the high-intensity action for the full span of a rugby match (80 min).

1.1. PHYSICAL DEMANDS OF RUGBY UNION MATCHES

Players are subdivided in two different playing positions: forwards (FWS), whose main role is to fight with the opposing team over the control of the ball, and backs (BKS), whose main purpose is, once the team has possession of the ball, attack the opponents' field and score a try. The detailed roles of a 15 players team are provided in Figure 1.1. Each position within a team has specific requirements which are typically based on speed, size and skill.

Figure 1.1 Rugby team positions and roles.



Rugby is a physically intense intermitted sport coupled with high force collisions. From a review of the literature it is possible to assess position specific differences in running demands at both professional and non-professional levels (Austin, Gabbett, & Jenkins, 2011; Lindsay, Draper, Lewis, Gieseg, & Gill, 2015; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). These studies have shown that rugby union is characterized by frequent bouts of high intensity activities like sprinting, tackling and fighting. A player is required to cover between 4500 and 7500 m per game, including 300 – 800 m above the threshold for high speed running, set at 14.4 km·h^{-1} (Dubois et al., 2017). These same studies show that the covered distance is dependent upon the position played. BKS cover overall a shorted distance during a game compared to FWS. FWS cover more distance at high speed running and sprinting (Lindsay et al., 2015). The lower distance covered and time spent running by FWS is counterbalanced by longer time engaged in static exertions (Austin et al., 2011), with the FWS being engaged more frequently and for longer periods of time in static holds, rack, and mauls compared to the BKS.

The positional specificity is consistent across different professional championships and is already present at the Junior level (Cunningham, Shearer, Drawer, Eager, et al., 2016; Deutsch & Reaburn, 1998). Cunningham and colleagues (Cunningham, Shearer, Drawer, Eager, et al., 2016) quantified the movement demands of elite international junior players during international tournaments (Six nations under 20, and World rugby under 20 championship). The same differences between FWS and BKS present at the senior level were found with the FWS covering less total distance (5370 ± 0830 m), and specifically less high speed distance (284.2 ± 134.9 m) and sprints (11.15 ± 5.06 m) compared to the BKS (6230 ± 800 m, 656.9 ± 182.7 m, 26.44 ± 7.47 m). When comparing junior and senior matches it possible to assess differences in specific positional groups (Cunningham, Shearer, Drawer, Pollard, et al., 2016), with the junior FWS first row performing more high speed running and accelerations then their older counterparts. On the opposite, the junior BKS midfielders performed less high speed running then the seniors. Regarding the first row, the difference can be explained by the fact that senior players are heavier and stronger and therefore, are more often engaged in static exertion activities. On the other hand, senior midfielders are possibly more frequently employed in direct line gain play by their teams compared to junior players (Cunningham, Shearer, Drawer, Pollard, et al., 2016).

1.2. PHYSICAL CHARACHTERISTICS OF RUGBY UNION PLAYERS

The diverging playing demands dictate the different physical characteristics required to players to be successful at the international level. Anthropometric profiles and physiological demands have been measured for each position. Notably, a recent systematic review has determined the anthropometric differences between players of different age and position (Geeson-Brown, Jones, Till, Chantler, & Deighton, 2020). The results from this meta-analysis highlighted the significantly higher body mass, fat mass, and fat free mass in senior players compared to junior players. The small differences in fat mass between age groups resulted in the senior players having a reduced body fat percentage compared to junior players. Regarding differences between positions, numerous studies displayed the variance in body size and composition (La Monica et al., 2016; K. Quarrie, Toomey, & Waller, 1996). It was possible to observe that BKS weight less, are shorter and present lower body fat percentage compared to FWS. FWS, being required to engage more frequently in static exertions are advantaged by the greater body mass, as it was also reported that rucking ability, tackling ability and force production in the scrum are directly correlated with body mass (K. Quarrie et al., 1996). However, the higher overall body mass and fat mass are detrimental when it comes to moving across the field. Speed and agility decrease as the body mass rises and the energy expenditure increases (Higham, Pyne, Anson, & Eddy, 2013). Even though partially detrimental, the heavier body mass has been suggested to carry some beneficial effects, for instance, body fat can protect the players during impacts. Yet, it is desirable that players increase their body mass through the accrual of lean body mass, due to the potential advantages in contact situations for additional momentum and stabilization (Duthie, Pyne, & Hooper Sue, 2003).

The differences in body size contribute to explain the systematic greater maximal strength and power displayed by FWS over BKS. During scrummaging the mean force ranges between 6210 N and 9090 N (K. L. Quarrie & Wilson, 2000), it is therefore paramount for FWS to be able to produce large amounts of force. In a cohort of recreational players FWS were shown to possess greater maximal force both in the upper body and the lower body (La Monica et al., 2016), while limited information is present for professional players. FWS have been reported to display higher force at lower isokinetic velocities, while BKS display higher forces at faster isokinetic velocities (Duthie et al., 2003). This velocity-specific ability for force production can be related to the different time frames in which players predominantly have to apply force during a rugby match, BKS in quasi isometric conditions like scrummaging and wrestling, FWS in sprints and change of direction activities, respectively. Lower body power production capabilities can be assessed from the vertical jump performance. BKS have been consistently reported do achieve higher vertical jump performance compared to FWS (Duthie et al., 2003; La Monica et al., 2016). Surprisingly, jump height has been reported to be inversely related to the level of practice (Duthie et al., 2003), with lower level players scoring higher jump heights. This can be explained with the concurrent difference in body mass between playing levels. A higher caliber player is heavier, this trait is counterproductive towards reaching higher vertical jump measurements. When testing jumps with force plates (Hansen, Cronin, Pickering, & Douglas, 2011), it was possible to assess that differences in power and force production were indeed present between different playing levels. Professional players displayed greater absolute peak power, and absolute peak force. On the contrary, no differences in relative peak power and relative peak force were present, suggesting the importance of larger body size in discriminating between competitive levels.

Differences in playing activities, body dimensions, and strength and power level consequently lead to diverging sprint performances between FWS and BKS. In fact, BKS, given their smaller body dimensions accelerate and decelerate more easily (Owen, Venter, Toit, & Kraak, 2015). When linear speed is tested, BKS consistently achieve faster times and higher speed values (Hansen et al., 2011; K. Quarrie et al., 1996). BKS sprint times over short distances, up to 40 m, are even comparable to those reported for track sprint athletes (Dowson, Nevill, Lakomy, Nevill, & Hazeldine, 1998).

A high level of aerobic fitness is paramount in rugby as the sport demands for the repetition of high intensity activities for the entire duration of the match. Aerobic fitness can be measured through the maximal oxygen consumption (vO2max) (McMahon & Wenger, 1998). The actual importance of a high vO2max for players has been debated as, although being important. Elite professional rugby players have a moderate vO2max (~50 $ml·kg^{-1}·min^{-1}$) (Duthie et al., 2003), which is drastically lower than endurance athletes (~75 $ml·kg^{-1}·min^{-1}$) (Morgan & Daniels, 1994), and lower than other large field invasion sports like soccer (~61 $ml·kg^{-1}·min^{-1}$) (Slimani, Znazen, Miarka, & Bragazzi, 2019) and Australian rules football (~58 $ml·kg^{-1}·min^{-1}$) (Haycraft, Kovalchik, Pyne, & Robertson, 2017). Estimated vO2max results from a shuttle run test displayed greater values for BKS compared to FWS (K. Quarrie et al., 1996). This should indicate the higher level of aerobic fitness in BKS, however, the use of a shuttle run test to estimate vO2max presents its downturn. The presence of decelerations and accelerations can present a major factor impacting fatigue for heavier players. Indeed one study has shown a poor correlation between shuttle run test and vO2max (O'Gorman, Hunter, McDonnacha, & Kirwan, 2000). In the literature are reported values of absolute vO2max exceeding 5.0 $l·min^{-1}$ for FWS players (Duthie et al., 2003), indicating high aerobic power production capabilities, that can be carried out during a game in the form of scrummaging, tackling and mauling.

1.3. RESISTANCE TRAINING IN RUGBY UNION

Rugby players are required to possess considerable amounts of lean body mass, to be strong, powerful, and fast to succeed in the game. A common modality to achieve such goals is resistance training. Resistance training programs can be either directed towards increasing muscular cross sectional area and therefore lean body mass (Schoenfeld, Grgic, Ogborn, & Krieger, 2017; Schoenfeld et al., 2014), improve strength and power levels (DeWeese, Hornsby, Stone, & Stone, 2015b, 2015a), 9and improve sprint performance (Deweese, Bellon, Magrum, Taber, & Suchomel, 2016). The large variability of stimuli and effectiveness provided by resistance training have contributed to this training modality popularity and spread for rugby union strength and conditioning programs (Corcoran & Bird, 2009; Mills, McMaster, & Smith, 2018). Because of the large stimulus necessary to achieve adaptations in trained athletes, and the relatively long recovery period necessary to reestablish homeostasis following such stimulus (Morán-Navarro et al., 2017), resistance training usually serves a secondary role during in-season time. In-season resistance training sessions provide the possibility to maintain previously achieved improvements in strength or is used as a tool to acutely improve performance in the upcoming training session or matches (Cook, Kilduff, Crewther, Beaven, & West, 2014; Harrison, James, McGuigan, Jenkins, & Kelly, 2019). To gain considerable amounts of lean body mass and strength more strenuous and prolonged training is necessary (Schoenfeld, Grgic, et al., 2017; Suchomel, Nimphius, & Stone, 2016). Strength and conditioning coaches therefore plan for muscular hypertrophy and strength gains to be achieved during the pre-season and program resistance training sessions with increased volume and intensity during this time frame to achieve these specific goals (Argus, Gill, Keogh, Hopkins, & Beaven, 2010; Corcoran & Bird, 2009).

The most recent guidelines about resistance training programs for the pre-season are presented in a review by Corcoran and Bird (2009) for teams partaking in the Australian domestic championships. The training plan is articulated in three successive periods for a total length of 20 weeks, and follows a block periodized structure (Issurin, 2016). When compared to a concurrent periodization in trained men (Painter et al., 2012), a block periodized approach has been demonstrated to be effective in improving body mass maximal strength, while it provides superior benefits for improving isometric rate of force development. This added benefit can be crucial for a superior performance, expecially for FWS as are often engaged in isometric holds where they are required to rapidly express large amounts of force.

The RT program proposed by Corcoran and Bird (Corcoran & Bird, 2009) is articulated in three subsequent blocks. The first aimed towards gaining muscular hypertrophy, the second towards maximal strength and the third towards peak power in more specific movements. This order of adaptation is consistent with the mathematical model proposed by Zamparo and colleagues (Zamparo, Minetti, & di Prampero, 2002), according to which towards obtaining maximal power output, it is firstly necessary to improve muscle structural components like cross sectional area muscle architecture. This, alongside with improved recruitment by the central nervous system over the peripheral motor units and local factors as modification in fiber type and inhibition of co-contraction, leads to an improvement in maximal strength. Lastly, the development of specific movement co-ordination and the fine tuning of the motor pattern, leads to increased power.

A study involving rugby league professional players aimed to determine if changes in maximal squat strength were reflected in improved sprint times (Comfort, Haigh, & Matthews, 2012). Squat (SQ) 1RM and sprints over 5, 10, and 20 m were completed before and after 8 weeks of preseason block periodized training. The first four weeks consisted of strength training and the last four weeks consisted in power training. Both absolute and relative squat strength values showed significant increases, along with significantly lower sprint times at the end of pre-season training. Still, the Authors state that it is not clear if the improvements in sprint performance came as a direct consequence of increased strength or whether both are a function of the strength and power mesocycles incorporated into the players' preseason training. Regarding the hypertrophy phase proposed by Corcoran and Bird (2009), it was programmed for four resistance training sessions a week, with a routine split between upper body and lower exercises, performed for 3 sets (S) x 10 – 12 repetitions (R) for the first four weeks and 4 x 6 – 8 for the following four weeks. The following block was aimed towards improving maximal strength and consisted of three resistance training sessions per week, with S x R: 3 – 5 x 4 – 6. The last block, aimed towards power training, presented two resistance training sessions per week, organized with total body routines, and prescribes S x R 3 – 5 x 3 – 5 and employed more ballistic oriented exercises, weightlifting derivatives exercises like pulls, power cleans, and push presses (Suchomel, Comfort, & Lake, 2017; Suchomel, Comfort, & Stone, 2015). This broad approach to pre-season preparation is made possible by the reduced length of the rugby championship season in the southern hemisphere, which concedes 5 – 6 months of preparatory periods to players. In the northern hemisphere the longer competitive season provides teams, depending on the competitive level, only 2 – 4 months to get ready for the competition.

A shorter preparatory phase, typical of the northern hemisphere, should by no means consist in a restraining for implementing a block periodized approach. The effectiveness of a block periodized training lasting less than three months in improving lean body mass, strength, and power in well trained individuals (K. M. Carroll, Bazyler, et al., 2019; K. M. Carroll, Bernards, et al., 2019) and athletes alike (Painter et al., 2012) has been amply documented (Issurin, 2016).

A concurrent periodization approach has been implement for as short as 4 weeks (Argus et al., 2010). Of the three weekly resistance training sessions, one was targeted to hypertrophy, one to strength, and one to power. Improvements in fat free mass and a reduction in fat mass were observed alongside an increase in maximal strength tested by 1RM in the squat (SQ) and bench press (BP) exercises. Simultaneously, a reduction in power production capabilities was observable, with a decreased bench toss and vertical jump performance. These results are in accordance with the study previously presented by Painter and colleagues (Painter et al., 2012), and are explainable by the inadequate management of fatigue throughout the training. In both cases the exercise intensities were prescribed with the repetition maximum zone method (RM). This consists in indicating the number of R that the athlete should perform for each S of each exercise the overload used by the athlete has to be heavy enough not to concede any additional R at the end of each S. This approach provides the athlete with an overload that corresponds to an intensity that is always maximal relatively to number of R completed.

The effects RM prescription method on physical performance have been tested multiple times against other prescription modalities in contexts other than rugby, spanning from physically active men (Izquierdo et al., 2006), to well-trained individuals (K. M. Carroll et al., 2018), and to track and field athletes (Painter et al., 2012). Across the studies, results are consistently favoring prescription modalities that enable to more finely manage strain and fatigue and are summed up in a recent review on the topic (Thompson, Rogerson, Ruddock, & Barnes, 2020), which favor training away from failure. This is possibly a new path for training prescription for rugby union RT programs.

This thesis provides new insights in players selection and RT. Firstly it will be assessed whether anthropometric and physical characteristics can discriminate between international and national rugby union players. Then, it will be assessed which RT modality, comparing RT to failure and not to failure, can improve the most the selected discriminatory physical characteristics.

2. STUDY 1

ANTHROPOMETRICAL AND PERFORMANCE DIFFERENCES IN NATIONAL VS. INTERNATIONAL TALENT IDENTIFIED YOUTH RUGBY UNION PLAYERS

2.1. INTRODUCTION

Rugby union is a large field sport characterized by an alternation of high intensity efforts and rest. The high intensity efforts can either be static exertions (e.g. rucks, mauls, tackles) or dynamic activities (e.g. sprints, jumps) (Austin et al., 2011; Colomer, Pyne, Mooney, McKune, & Serpell, 2020). Players can be divided by their playing position in forwards (FWS) and backs (BKS). For each position, players are required to display a specific profile of static and dynamic exertions. FWS tend to be more often engaged in static exertions (Austin et al., 2011), while BKS in dynamic activities (Owen et al., 2015).

The diverse in-game tasks have resulted in a marked differentiation in players body type and physical characteristics at the professional level, with FWS being heavier and stronger (Argus, Gill, & Keogh, 2012), while BKS are faster (La Monica et al., 2016; K. Quarrie et al., 1996; D. J. Smart, Hopkins, & Gill, 2013). Furthermore, anthropometric (Geeson-Brown et al., 2020) and physical (Hansen et al., 2011) differences are present between junior and senior professional players. Senior players display higher body mass and a smaller percentage of body fat (Geeson-Brown et al., 2020), are faster and produce more absolute power and force in vertical jumps when compared to junior players (Hansen et al., 2011).

Specificities dictated by playing position demands and differences in competitive outcomes, help to explain why rugby federations have resorted to talent identification programs for players from a young age*,* with a tendency to recruit heavier and bigger players (Delahunt et al., 2013; Fontana, Colosio, Da Lozzo, & Pogliaghi, 2017). Analyzing data from draft camps, Fontana and colleagues (Fontana et al., 2017) could develop a linear model mixing anthropometric and physical characteristics to predict career paths outcomes (either national or international) in Italian 15 years old players. In the model, the strongest predicting variables have been identified as percentage of body fat and sprint times, with lower measures indicative of higher chances of international playing level.

In Italy, draft camps are the first stage of the talent identification program implemented by the Italian Rugby Federation. In fact, talent identified players can access to one of four zonal preparatory academies for U18 players, and then to the national academy for U20 players. The objective of the academy system is to select talented players and provide support and training aimed to long-term international success. Of relevance, a crucial experience offered to further selected players from the zonal and national academies, is the participation to international U18 and U20 tournaments.

A factor to be taken into account when dealing with selection in youth sport, is the relative age effect (Musch & Grondin, 2001). Players born in the first quarter of the year display a greater maturation status and physical development, which is advantageous towards selection. The relative age effect has been reported also in senior rugby FWS players (Kearney, 2017), thus, it must be taken into account when dealing with players selection at all levels in rugby.

Therefore, the first aim of this study is to assess whether age, anthropometric, and physical characteristics differences are already manifest in talent identified U20 players between FWS and BKS involved in the national U20 national academy. Furthermore, the second aim is to assess whether these traits can differentiate between internationally selected and non-selected players. It will be also attempted to develop a predictive model able to discriminate between international selected and non-selected players from age, anthropometrics, and physical traits.

2.2. METHODS

Subjects

For the present study data from 72 young talent identified rugby players were assessed (age = 19.0 ± 0.5 years, height = 1.86 ± 0.08 m, body mass = 101.1 ± 13.4 kg). The subjects played for the national selection academy team and were selected at a national level in the U20 age group. Sixty-eight of the subjects had been previously playing and training for regionally selected academy teams in the U18 age group. Players completed five to nine weekly training sessions of the duration of two to three hours each. Additionally, players competed in a championship at the second level of the national rugby federation hierarchy (Serie A). The championship took place from October to May and provided one match day per week. Internationally selected players competed in the World Rugby Under 20 Championship, held in June.

Experimental Approach

To assess the traits characterizing international level young rugby players a retrospective study design was employed. Data was retrieved from national talent identified players during two consecutive seasons. The players anthropometric characteristics and physical performances in vertical jump, sprint, maximal strength, and aerobic fitness were tested by experienced strength and conditioning coaches. Data collection was part of a regular physical assessment process performed during three testing occasions, in the months of September, January, and May. As it was frequent for players to be injured and not capable of concluding the whole physical assessment, the best performance out of the three testing occasions was considered.

Procedures

Anthropometric

Players' height was measured with a regulated stadiometer at the nearest 0.1 cm, players' body mass was measured with a digital scale at the nearest 0.1 kg. Each measure was assessed twice and the average of the two was considered for further procedures. Body mass index (BMI, kg·m^{-2}) was computed as:

$$BMI = \frac{body\ mass\ (kg)}{(height\ (m))^2}$$

Skinfold thickness was measured at 7 sites (biceps, triceps, subscapular, supra-iliac, abdomen, mid-thigh, and calf) using calibrated calipers (Harpenden, British Indicators Ltd, St Albans, UK) (Jace A. Delaney et al., 2016). All sites were on the right side of the body. Each skinfold was measured twice, and the mean of the 2 measures was used for analysis. If the 2 measures differed by more than 5%, a third measure was taken. In this case, the median of the three measurements was used for subsequent analysis. To estimate fat mass the following equation was used (Withers, Craig, Bourdon, & Norton, 1987):

$$Fat\ mass\ (\%) = \frac{495}{1.0988 - (0.0004 \cdot \sum 7\ skinfolds\ (mm))} - 450$$

Vertical Jump

Players' vertical jump ability was assessed through the countermovement jump with arms held in akimbo position (CMJ). Players were asked to wait, after a countdown, for the operator's signal to perform the CMJ. The verbal directions given by the operator were "three, two, one, jump!". Players performed two warm-up jumps at 50% and 75% of their subjectively perceived maximal effort, respectively. Players then performed at three jumps at the best of their perceived effort. A 60 s recovery period was conceded between attempts. Players were verbally incited by the operator to jump the highest possible. If the players landed with the lower limbs bent, the attempt was discarded, and he was asked to perform an additional jump. CMJ jump height (h) was assessed thanks to an optoelectrical system composed of two one m long bars (Optojump Next, Microgate, Bolzano, Italy) (Glatthorn et al., 2011). The player stood between the bars and upon jumping, the system started a chronometer which was later stopped when the player landed between bars. From the flight time (ft) registered, the h (m) could be computed thanks to the equation (Lees & Fahmi, 1994):

$$\mathrm{CMJ}h = \frac{g \cdot ft^2}{8}$$

where g is the acceleration due to gravity (9.81 $m \cdot s^{-2}$).

To estimate peak power (pp, in W) produced by the athlete during the jumping motion, this equation was used (Evertett A. Harman, Rosenstein, Frykman, Rosenstein, & Kraemer, 1991):

$$CMJpp = 61.9 \cdot h + 36.0 \cdot body\ mass + 1822$$

For statistical analysis purposes the average of the two best measurements was considered.

Sprint

Players' sprint ability was tested on a 30 m sprint, with split time at 10 m. The split time at 10 m is mostly indicative of acceleration capabilities, while the 30 m time, in a field sport context, is mostly indicative of maximal speed capabilities (Duthie et al., 2003). The sprints were performed on an outdoor synthetic turf.

Players performed an extensive warm up before the test, comprising five min low intensity aerobic activity (jog), 10 min dynamic stretching exercises involving the muscles of the legs, thighs, hips and trunk, and five min sprint drills (skipping and strides) performed over 20 m. Then, players performed two 30 m warm-up sprints, the first one at 50% and the second one at 75% of their subjectively perceived maximal effort, respectively.

Players performed three maximal effort sprints, starting from a crouching position, with five min recovery between attempts. Players placed the foremost foot 0.3 m behind the starting line and started the sprint after the operator command "Go". The players were verbally incited by the operator to sprint as fast as they could. Sprint times were collected using optoelectrical gates (Witty, Microgate, Bolzano, Italy) positioned at the starting line (height set at 0.3 m), 10 m and 30 m line (height set at

1.0 m) (Nuell et al., 2020; Ramos-Campo et al., 2020). For statistical analysis purposes the average of the best two out of three times was considered. Additionally, momentum (mm, kg·m·s^{-1}) was computed for 10 m and 30 m sprints using the equations (Barr, Sheppard, Gabbett, & Newton, 2014):

$$10mm = body\ mass\ \cdot \frac{10}{10t}$$

$$30mm = body\ mass\ \cdot \frac{30}{30t}$$

Maximal Strength

To assess players' maximal strength, the one repetition maximum (1RM) was tested for the following barbell exercised: back squat (SQ), deadlift (DL), bench press (BP), and bench row (BR). Players were allowed to wear a weightlifting belt during testing but no knee or elbow wraps nor lifting straps were conceded. The protocol used to assess the 1RM was standardized and is reported in Table 2.1 (Haff & Triplett, 2015).

Table 2.1 Procedures for 1RM testing,

	Back squat, deadlift	**Bench press, bench row**
1.	10 reps with self-selected light overload	10 reps with self-selected light overload
2.	1 min rest	1 min rest
3.	5 reps with a 15 – 20 kg heavier overload	5 reps with a 5 – 10 kg heavier overload
4.	2 min rest	2 min rest
5.	3 reps with a 15 – 20 kg heavier overload	3 reps with a 5 – 10 kg heavier overload
6.	3 min rest	3 min rest
7.	1 rep with a 15 – 20 kg heavier overload	1 rep with a 5 – 10 g heavier overload
8.	Repeat from 6. If the player fails 3 min rest	Repeat from 6. If the player fails 3 min rest
9.	1 rep with a 5 – 10 kg lighter overload	1 rep with a 0 – 5 kg lighter overload

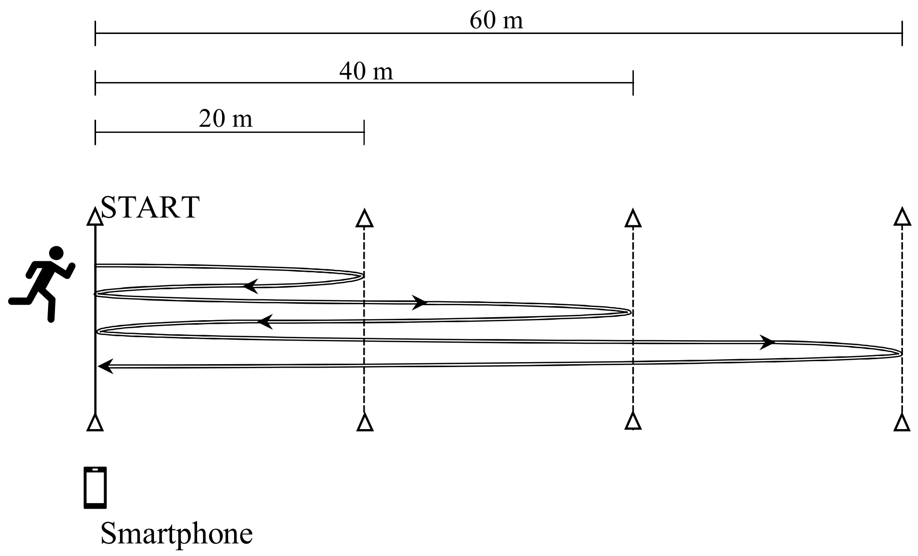
Modified from Haff & Triplett, 2015.

Testing was supervised by experienced strength and conditioning coaches. SQ was deemed valid if the player could squat to parallel (hip crease below upper part of the patella) (SQ1RM). DL was deemed valid if the player could stand and fully extend knee and hip joints (DL1RM). BP was deemed valid if the player touched the chest with the barbell before completing the movement (BP1RM). BR was deemed valid if the player could touch the bottom part of the bench with the barbell (BR1RM).

Aerobic fitness

Aerobic fitness was tested through the Bronco running test (Miles et al., 2019). The Bronco test is a widely used test in rugby and is a continuous running test of 1200 m with change of directions. The test was performed on a synthetic grass turf. Players started at the starting line and, after the operator command, run for 20, then return to the starting line, run for 40 m, then return to the starting line, run for 60 m, then return to the starting line. To mark the distances to be run, cones were placed at 0, 20, 40, and 60 m from the starting line. Completion of the 20-40-60 m shuttles consisted in one repetition, and athletes had to complete 5 repetitions as quickly as possible to finish the test (Figure 2.1). The operator verbally encouraged the players to run as fast as they could and to complete the test in the shortest time possible. The test was filmed with a smartphone camera (iPhone 7, Apple, Cupertino, CA, USA) set parallel to the starting line. Camera filming speed was set at 60 fps, with resolution of 720 p. Times to complete the test were assessed using a video analysis software (Kinovea 0.8.15 for Windows) (Puig et al., 2019). The stopwatch provided by Kinovea software was started at the operator command and stopped when the athlete completed the 1200 m run (Duca, Trecroci, Perri, Formenti, & Alberti, 2020).

Figure 2.1 Layout for Bronco running test.



Note: the 20-40-60 m course was repeated 5 times to complete the test.

Statistical Analysis

Data for the independent variables is shown as mean ± standard deviation. The dependent variables were "selection", assessing whether a player was selected for international competitions, and "position", either FWS or BKS. To assess the differences between selected and non-selected players multiple two factors (2x2) analysis of variance (ANOVA) were employed. The between subjects' factors were "selection" and "position". Reliability of the measurements was quantified by a two-way mixed intraclass correlation coefficient (ICC) for average measurements (ICC type 3, k) and standard error of measurement ($SEM = \text{standard deviation} \cdot \sqrt{(1 - ICC)}$). Statistical analysis was performed using SPSS v.21.0 (IBM Corp., Armonk, NY, USA) and a customized spreadsheet (Excel, Microsoft, Redmond, WA, USA).

Furthermore, the variables that presented a significant selection effect were used as independent variables in multiples logistic regression analysis, while selection was the dependent variable. To perform the analysis using the software R 3.6.1. Statistically significative results are presented according to Smart et. al (J. Smart, Sutherland, Watkinson, & Gill, 2004). The script used is provided in the appendix. Statistical significance level was set at $p=0.05$.

2.3. RESULTS

ICC and SEM resulted 0.981 and 0.6% for fat mass respectively, 0.978 and 0.008 m for CMJh, 1.000 and 0.000 W for CMJpp, 0.964 and 0.018 s for 10t, 0.994 and 0.017 s for 30t, 0.995 and 4.570 N·m for 10mm, 0.999 and 2.481 N·m for 30mm, respectively.

Descriptive statistics for the dependent variables are presented in Table 2.2,

Table 2.2 Descriptive statistics for dependent variables

Position	**Forwards (n=42)**		**Backs (n=30)**	
Selection	**Non-selected (n=27)**	**Selected (n=15)**	**Non-selected (n=16)**	**Selected (n=14)**
Age (yrs)	19 ± 0.6	19.4 ± 0.5	18.9 ± 0.5	18.9 ± 0.5
Height (m)	1.89 ± 0.08	1.87 ± 0.06	1.8 ± 0.08	1.83 ± 0.04
Body mass (kg)	108.5 ± 6.9	113.4 ± 8.7	87 ± 8.9	89.6 ± 6.4
BMI ($kg{\cdot}m^{-2}$)	30.4 ± 3	32.5 ± 2.8	26.8 ± 2.6	26.9 ± 1.7
Fat Mass (%)	0.15 ± 0.04	0.17 ± 0.04	0.11 ± 0.02	0.1 ± 0.02
CMJh (m)	0.38 ± 0.04	0.38 ± 0.05	0.43 ± 0.05	0.45 ± 0.05
CMJpp (W)	5753 ± 249	5928 ± 314	4979 ± 318	5077 ± 233
10t (s)	1.84 ± 0.09	1.83 ± 0.06	1.74 ± 0.07	1.71 ± 0.08
30t (s)	4.41 ± 0.2	4.42 ± 0.11	4.15 ± 0.13	4.08 ± 0.15
10mm (N·m)	590 ± 40	621 ± 50	500 ± 53	525 ± 43
30mm (N·m)	739 ± 50	769 ± 54	630 ± 68	660 ± 60
SQ1RM (kg)	167.8 ± 28.8	189.5 ± 25.8	148.4 ± 19.8	172 ± 15.9
DL1RM (kg)	187.6 ± 27.2	211 ± 22.6	164.1 ± 23.7	176.8 ± 22.1
BP1RM (kg)	122.1 ± 17.7	133 ± 17.6	115.5 ± 21.3	123.6 ± 15
BR1RM (kg)	104 ± 15	112.3 ± 5.6	94.1 ± 15.2	98.6 ± 17.5
Bronco (s)	312.5 ± 15.9	305.8 ± 11.8	281.7 ± 18.4	283.4 ± 13.3

BMI = Body mass index, CMJh = countermovement jump height, CMJpp = countermovement jump peak power, 10t =10 m sprint time, 30t = 30 m sprint time, 10mm = 10 m sprint momentum, 30mm = 30 m sprint momentum, SQ1RM = back squat one repetition max, DL1RM = deadlift one repetition max, BP1RM = bench press one repetition max, BR1RM = bench row one repetition max.

ANOVA

No interaction (position x selection) effect was present for any of the dependent variables (Table 2.3). Body mass (p=0.048*) (Figure 2.2), CMJpp (p=0.047*) (Figure 2.3), 10mm (p=0.014*) (Figure 2.4), 30mm (p=0.037*) (Figure 2.5), SQ1RM (p<0.001*) (Figure 2.6), DL1RM (p=0.004*) (Figure 2.7), and BP1RM (p=0.035*) (Figure 2.8) displayed a significant selection effect. A statistically significant effect for position was present for Height (p<0.001*), Body mass (p<0.001*), BMI (p<0.001*), Fat Mass (p<0.001*), CMJh (p<0.001*), CMJpp (p<0.001*), 10t (p<0.001*), 30t (p<0.001*), 10mm (p<0.001*), 30mm (p<0.001*), SQ1RM (p=0.003*), DL1RM (p<0.001*), BR1RM (p=0.001*), Bronco (p<0.001*), but not for Age and BPRM (Table 2.3).

Table 2.3 Results for the ANOVA

	SELECTION		**POSITION**		**INTERACTION Selection x Position**	
	F (1, 68)	Sig.	F (1, 68)	Sig.	F (1, 68)	Sig.
Age (yrs)	2.000	0.162	3.677	0.059	1.984	0.164
Height (m)	0.000	0.992	16.004	<0.001*	1.857	0.177
Body mass (kg)	4.050	0.048*	145.918	<0.001*	0.333	0.566
BMI ($kg \cdot m^{-2}$)	2.819	0.098	50.626	<0.001*	2.270	0.137
Fat Mass (%)	0.117	0.734	40.984	<0.001*	2.174	0.145
CMJh (m)	1.132	0.291	27.735	<0.001*	1.873	0.176
CMJpp (W)	4.104	0.047*	144.881	<0.001*	0.318	0.575
10t (s)	1.474	0.229	32.015	<0.001*	0.128	0.721
30t (s)	0.378	0.541	57.878	<0.001*	0.990	0.323
10mm (N·m)	6.375	0.014*	69.338	<0.001*	0.084	0.772
30mm (N·m)	4.545	0.037*	60.811	<0.001*	0.001	0.975
SQ1RM (kg)	14.645	<0.001*	9.726	0.003*	0.023	0.879
DL1RM (kg)	9.068	0.004*	23.162	<0.001*	0.793	0.376
BP1RM (kg)	4.625	0.035*	3.326	0.073	0.098	0.755
BR1RM (kg)	3.441	0.068	11.667	0.001*	0.307	0.581
Bronco (s)	0.447	0.506	51.031	<0.001*	1.290	0.260

BMI = Body mass index, CMJh = countermovement jump height, CMJpp = countermovement jump peak power, 10t =10 m sprint time, 30t = 30 m sprint time, 10mm = 10 m sprint momentum, 30mm = 30 m sprint momentum, SQ1RM = back squat one repetition max, DL1RM = deadlift one repetition max, BP1RM = bench press one repetition max, BR1RM = bench row one repetition max, * = statistically significative effect at the level of $p<0.05$.

Figure 2.2 Bar graph for players' body mass.

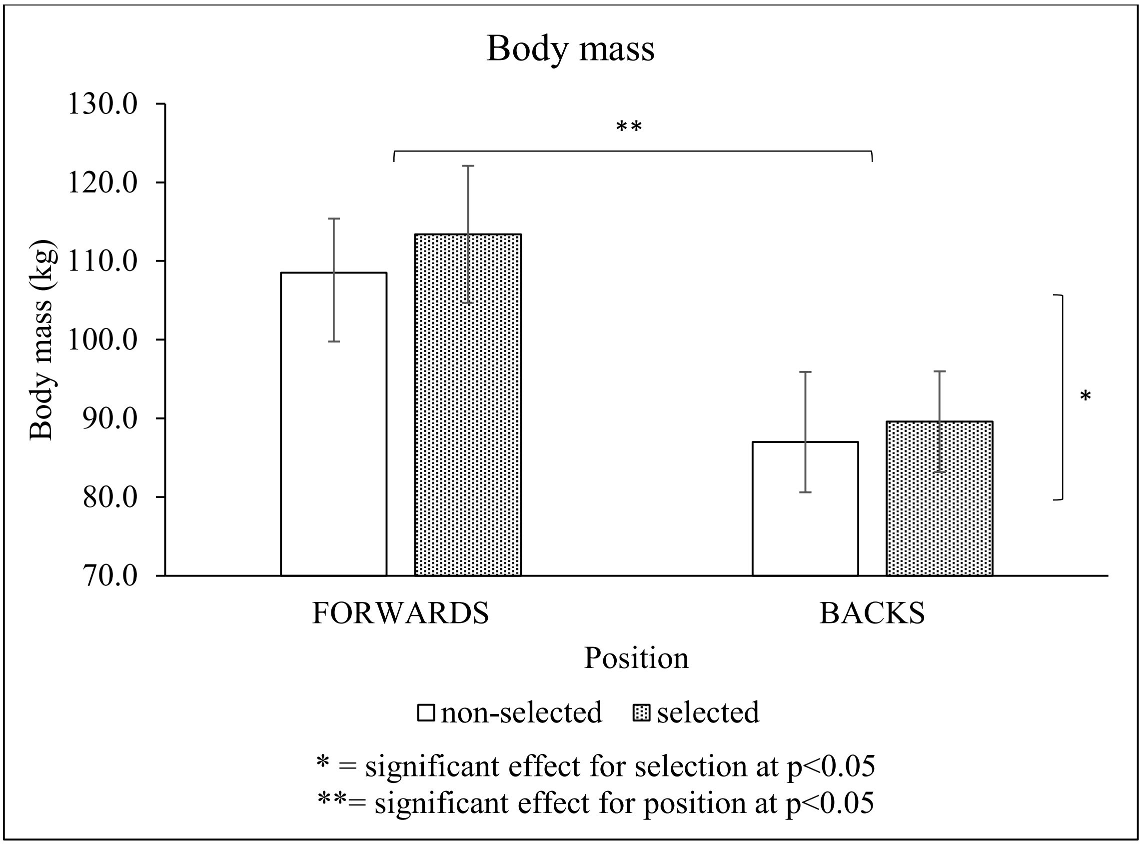


Figure 2.3 Bar graph for players' countermovement jump peak power.

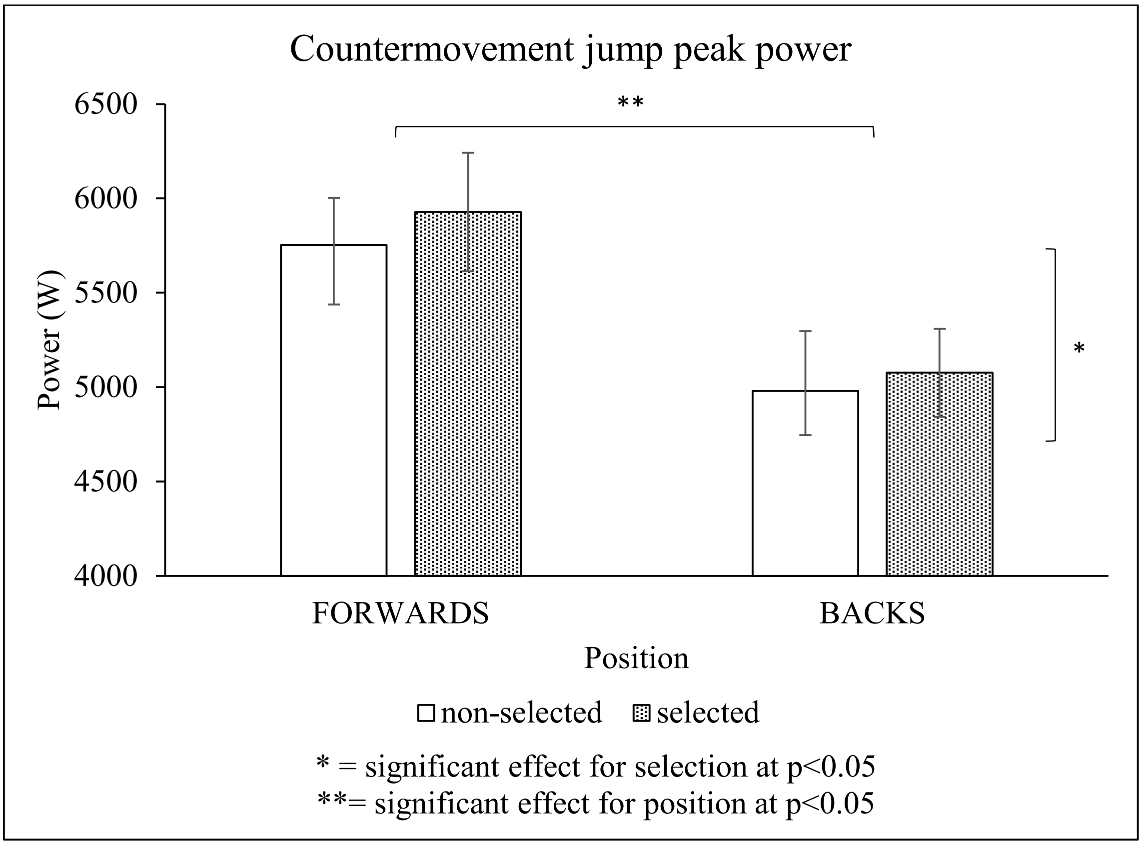


Figure 2.4 Bar graph for players' 10 m sprint momentum.

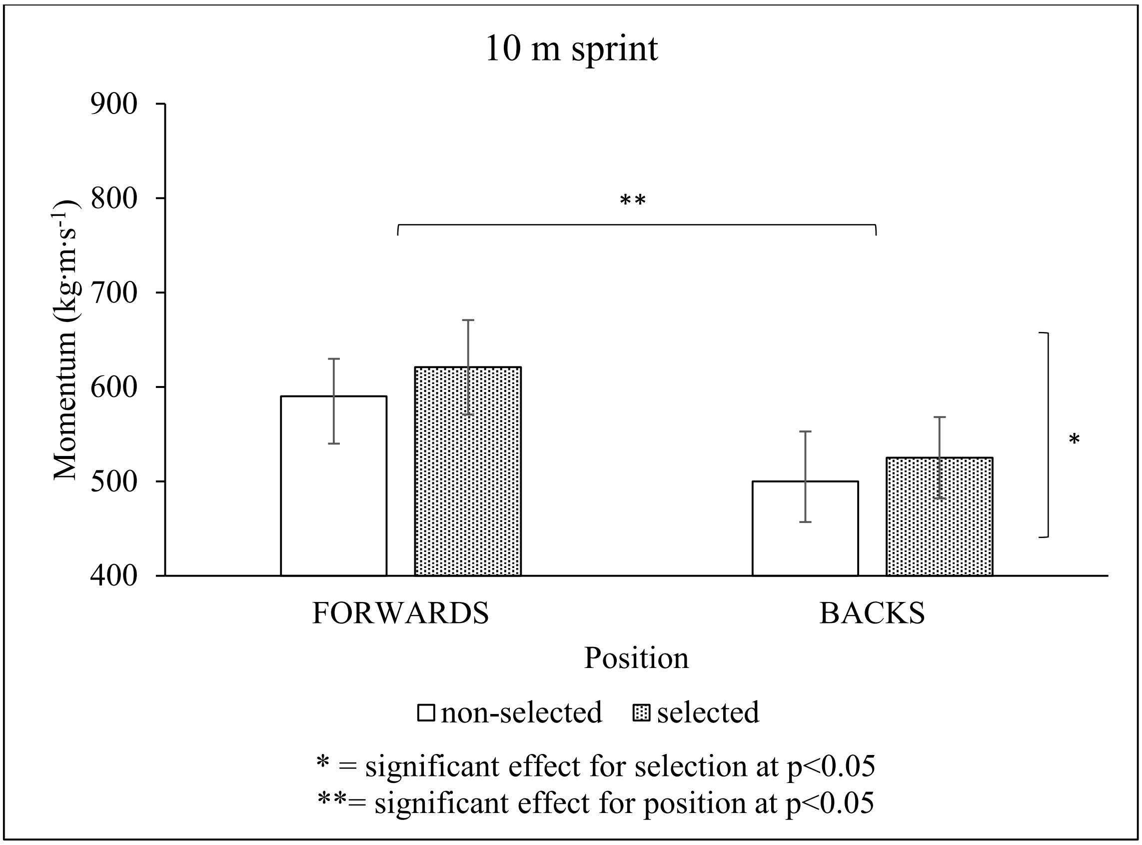


Figure 2.5 Bar graph for players' 30 m sprint momentum.

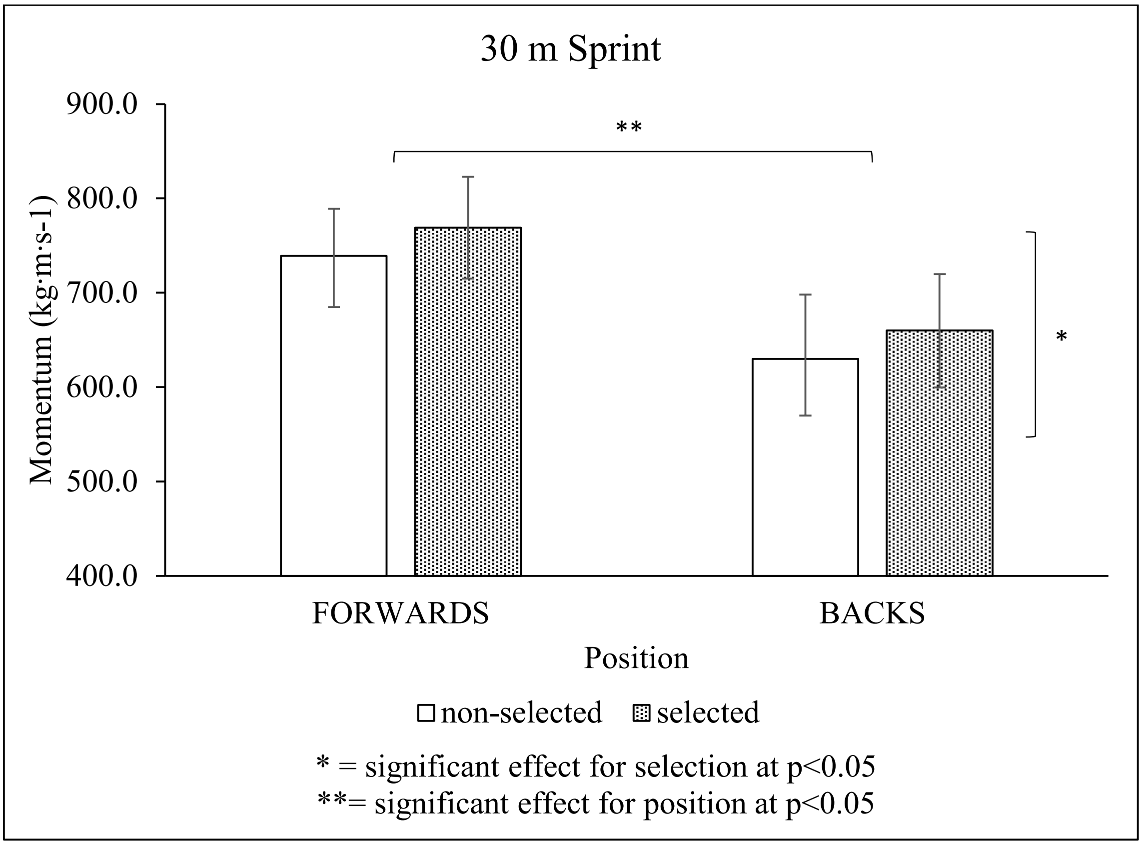


Figure 2.6 Bar graph for players' back squat one repetition max (1RM).

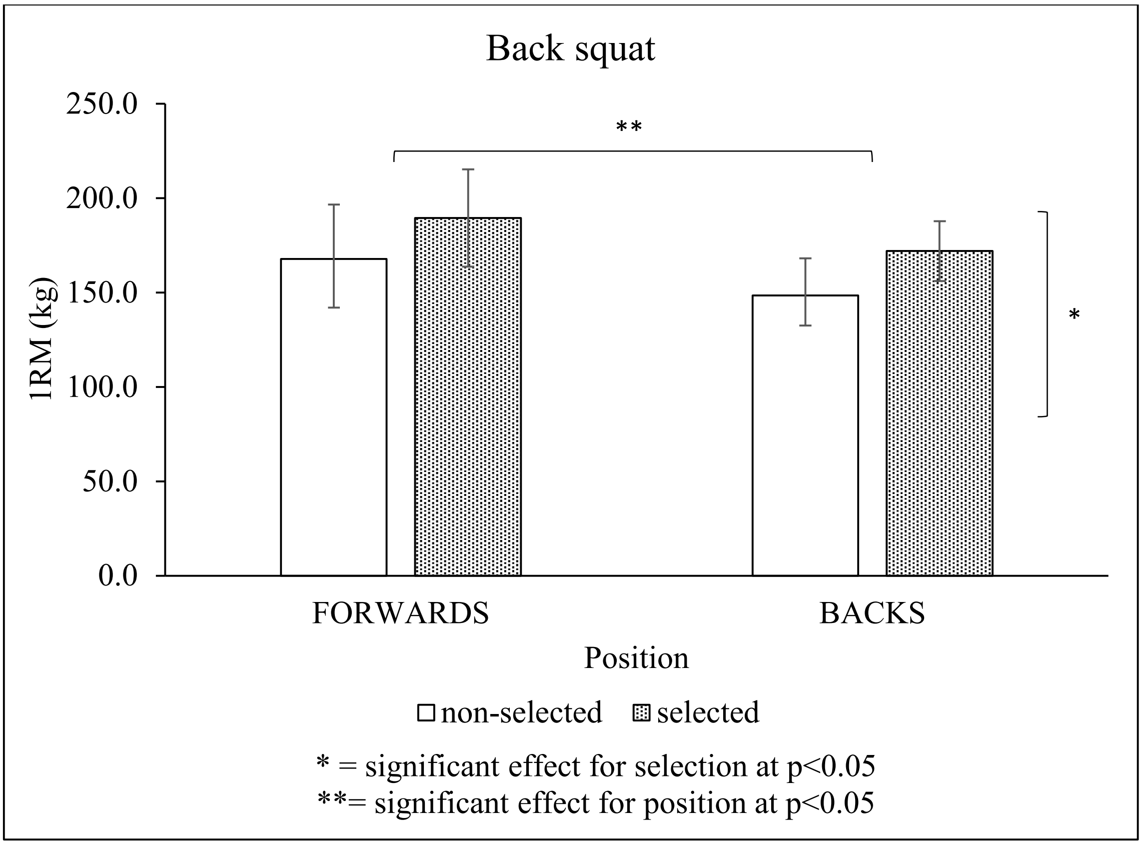


Figure 2.7 Bar graph for players' deadlift one repetition max (1RM).

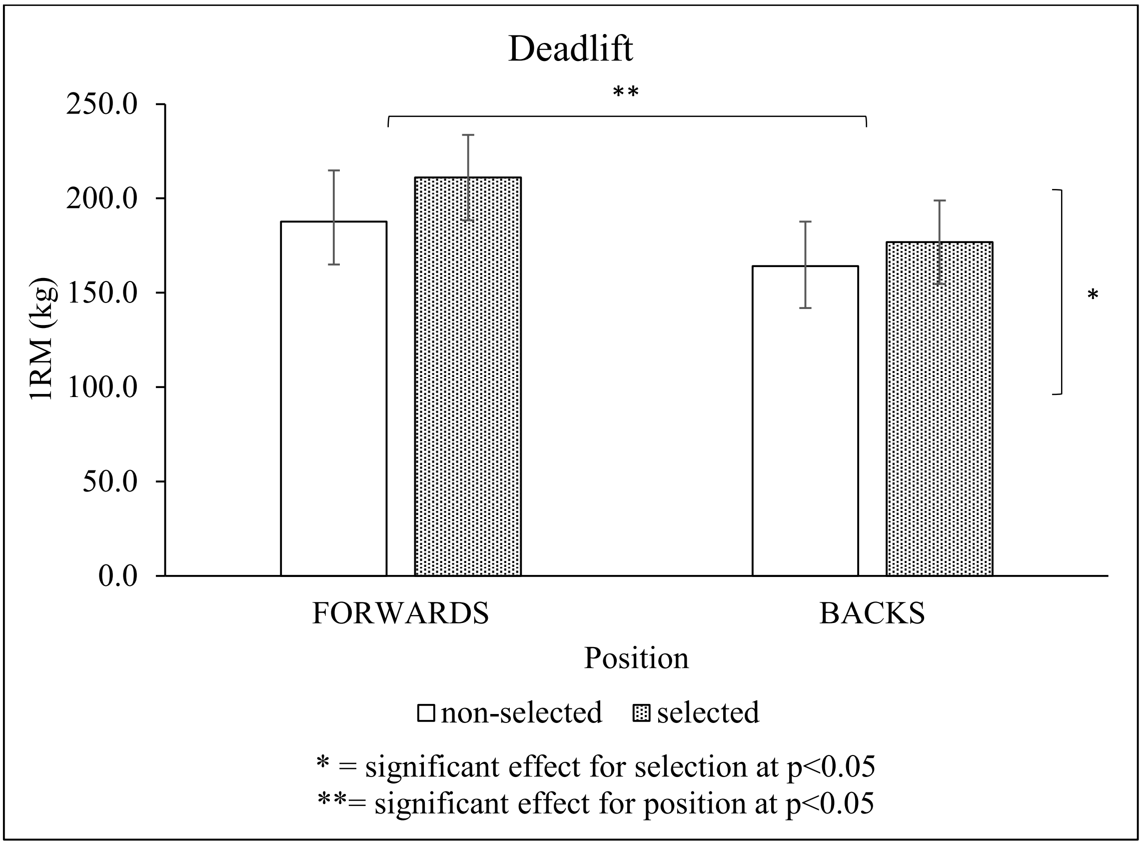
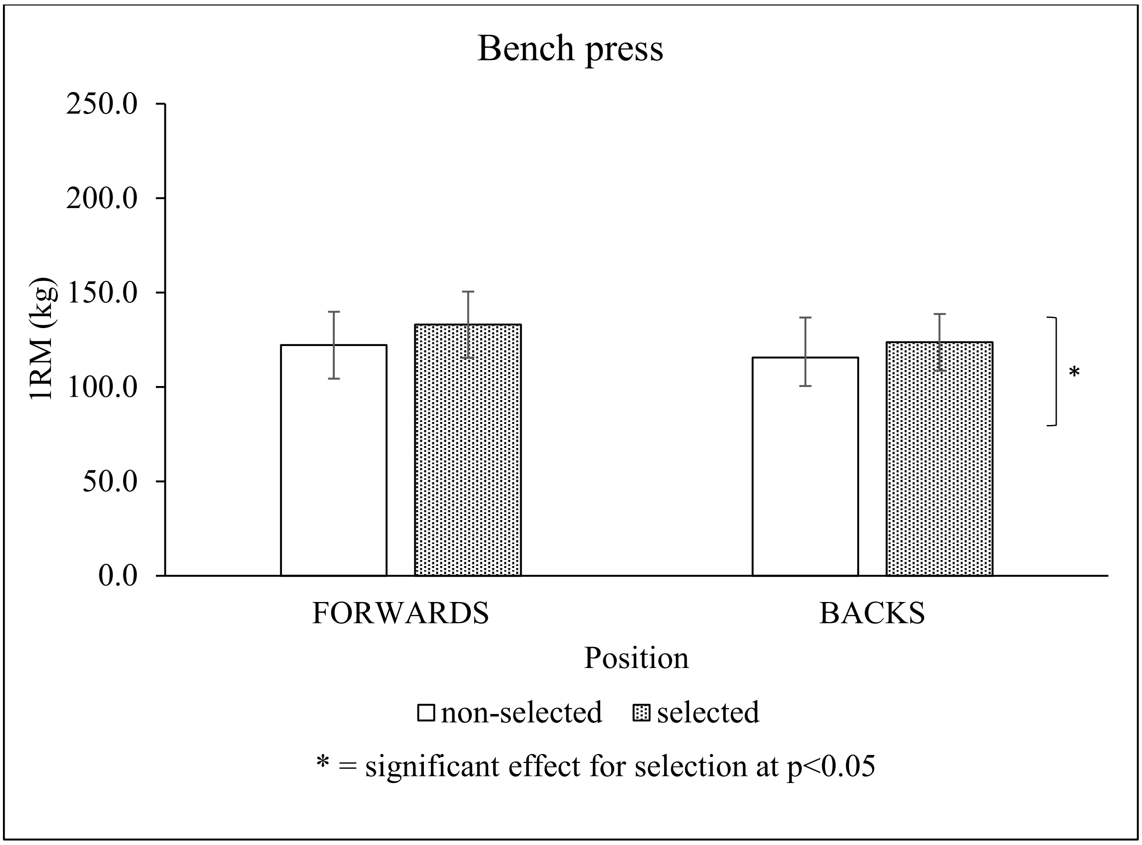


Figure 2.8 Bar graph for players' bench press one repetition max (1RM).



Logistic Regression

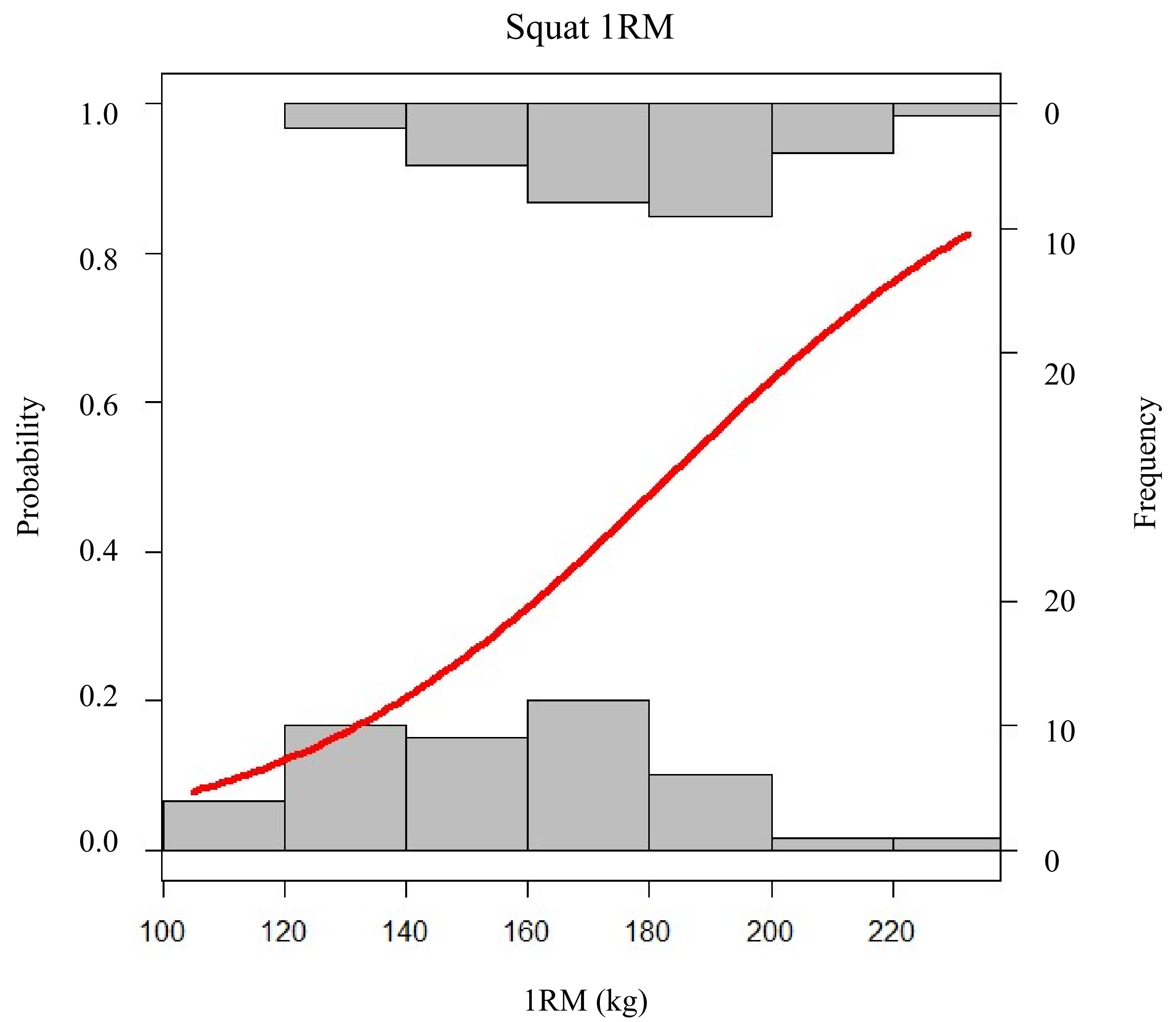
The results for the logistic regression analysis are shown in Table 2.4. A statistically significative was present only for SQ1RM (p=0.015*) (Figure 2.9)

Table 2.4 Logistic regression analysis coefficients

	Estimate	**Std. Error**	**Z value**	**p**
(Intercept)	-234.600	228.200	-1.028	0.304
Body mass	-4.480	4.387	-1.021	0.307
CMJpp	0.124	0.124	1.004	0.315
10mm	0.035	0.019	1.804	0.071
30mm	-0.028	0.020	-1.410	0.159
SQ1RM	0.044	0.018	2.427	0.015*
DL1RM	-0.004	0.017	-0.255	0.799
BP1RM	-0.001	0.020	-0.056	0.955

CMJpp = countermovement jump peak power, 10mm = 10 m sprint momentum, 30mm = 30 m sprint momentum, SQ1RM = back squat one repetition max, DL1RM = deadlift one repetition max, BP1RM = bench press one repetition max, * = statistically significative effect at the level of p<0.05.

Figure 2.9 Logistic regression analysis plot for back squat 1RM.



Notes: histograms represent the distribution of the players squat 1RM. The line is the predicted probability that a player is selected.

2.4. DISCUSSION

The main findings from the present study are first that BKS and FWS present significative differences in most of the investigated variables. Second, body mass and lower body power and strength can differentiate between non-internationally and internationally selected players. Specifically, SQ1RM displaying the strongest capabilities at predicting the selection outcome.

The position effect from the ANOVAs tests confirms that FWS are heavier, stronger, and capable of exerting superior lower body absolute power when compared to BKS. On the other hand, BKS display superior sprinting and jumping abilities and achieved faster times in the Bronco test than FWS. Consistent with the literature (Argus et al., 2012; K. Quarrie et al., 1996), anthropometric differences are present between FWS and BKS, with FWS being taller, heavier, and display higher level of BMI and percentage fat mass. These results can be explained by the positive outcomes of talent identification program that enables to recruit players with body types matching the positional game requests.

Regarding jumping ability, BKS jumped higher than FWS, while FWS displayed higher peak power than BKS. CMJh is determined by take of velocity, which is dependent on the resultant force applied on the players center of mass (Hara, Shibayama, Takeshita, Hay, & Fukashiro, 2008). The resultant force is the difference between the force applied by the athlete into the ground and the resistance offered by the athlete's body mass. Therefore, heavier athletes present a greater resistance to overcome, resulting in inferior jumping height, and accompanied by a superior power production.

Similarly to jump results, BKS displayed faster sprint times than FWS, confirming the plethora of studies reporting the FWS to be faster than the BKS (Hansen et al., 2011; La Monica et al., 2016; K. Quarrie et al., 1996). The marked differences in body mass between playing positions, as a consequence of recruitment and specific training, can be identified as the fundamental reason for this result. This same body mass gap is the key factor when interpreting sprint momentum results, with the BKS displaying greater 10mm and 30mm than the FWS, in accordance with the literature (Nakamura et al., 2016; K. Quarrie et al., 1996).

Between positions maximal strength differences are present for all the exercises tested. FWS systematically displayed higher levels of both lower limbs and upper limbs maximal strength when compared to BKS. These results are in accordance with the literature (Ball, Halaki, Sharp, & Orr, 2018; La Monica et al., 2016). Albeit testing weaker American university rugby players (FWS SQ1RM = 164.6 ± 43.0 kg, FWS BP1RM = 121.1 ± 30.3, FWS SQ1RM = 108.5 ± 31.5 kg, FWS BP1RM = 89.5 ± 20.2), the Authors found large position specific differences, with FWS being stronger than BKS in both SQ and BP 1RM. Similarly, Ball and colleagues found U20 academy FWS to be stronger in the SQ, DL, and BP. To the authors' knowledge, this is the first study to report position specific differences in BR1RM for rugby union players. This difference, still, is consistent with the overall higher strength levels displayed by FWS and attributable to the underlying differences in body mass and training specificity. FWS training puts a greater emphasis on maximal strength, due to their greater involvement in static exertions (rucks, mauls) during a rugby match (Austin et al., 2011).

BKS displayed faster Bronco test times and therefore better aerobic fitness compared to BKS. This result is in accordance with the literature (Ball et al., 2018; La Monica et al., 2016; K. Quarrie et al., 1996), although it has to be pointed out that a shuttle run, presenting frequent changes of direction characterized by deceleration and acceleration phases, though specific to in-game movements, can present a bigger toll on peripheral muscle fatigue on heavier players – penalizing FWS over BKS. Furthermore, FWS players are more often engaged in prolonged static exertions, that are more reliant upon upper body power production, which is indeed not detectable by a shuttle run test.

Internationally selected players differed from the non-selected players only in few variables, as the selected players were identified to be heavier, stronger and more powerful than the non-selected ones. Contrary to what was possible to expect (Kearney, 2017), age did not influence selection, as no difference was present between selected and non-selected players.

Internationally selected players have a greater body mass but were not taller nor presenting differences in BMI nor percentual body fat. The higher body mass represent an advantage, carrying greater inertia during contact, and therefore facilitating overcoming the opponents (Barr et al., 2014).

Vertical jump ability, measured by height reached, showed no difference. This result is in accordance with Duthie and colleagues (Duthie et al., 2003) results, showing even that jump height was higher in lower level players. On the other hand, CMJpp was higher in internationally selected players. This result is in accordance with Hansen and colleagues (Hansen et al., 2011), as professional players in fact scored greater absolute peak power in loaded jumps compared to elite junior players.

Additionally, while sprint times showed no difference, sprinting momentum can discriminate between selected and non- selected players. Carrying more mass into contact has been previously demonstrated to be directly correlated with the players' ability to dominate tackles in Sevens rugby players (Ross, Gill, Cronin, & Malcata, 2015), this same effect is sought after by in rugby union.

Internationally selected players proved to be stronger in the SQ, BP and DL, while no difference was present for the BR. Differences in strength levels between different playing levels have been report by numerous authors (K. Quarrie et al., 1996; D. J. Smart et al., 2013), those differences can be also interpreted in consequence to higher level players being bigger and heavier, and therefore capable of greater force production. As stated before, being stronger gives an athlete a competitive advantage in a sport including situations where wrestling against an opponent for the possession of the ball is required (Austin et al., 2011). This is especially true for FWS players that must push, pull and resist to their opponents for multiple times during a match in situations like scrums, rucks, and mauls (Austin et al., 2011).

Regarding the Bronco test, no differences between selected and non-selected players were found, in accordance with the literature (Duthie et al., 2003), suggesting secondary role for aerobic fitness development in training for rugby union players.

Considering the logistic regression analysis, only SQ1RM was identified as significant predictor of selection. This is in contrast with previous literature (Fontana et al., 2017), that presented faster sprint times and lower body fat as the most important predictors of long term success. The variables assessed in that study were body mass, height, fat mass, static squat jump h, CMJh, 15 m t and 30 m t. Data was collected over four years, for a total number of 531 junior male players, while the present study presents data for 72 players over two years. The larger sample size in Fontana and colleague study is representative of larger cohort, four time as big as the one present in this study per year. A larger pool is therefore representative of players with more varied talent levels. Furthermore, in the model, no measurements of sprint momentum, jumping power or maximal strength were included – the only variables presenting a significant effect on selection in the present study. It is therefore possible that a model including those variables would have presented stronger predictive capabilities.

The lack of interaction effect for any of the investigated variables must be pointed out. It therefore appears that, regardless of playing position, all players must excel over the same broad spectrum of power and strength characteristics. This information can ease the work of the strength and conditioning coaches as the objectives of strength and conditioning sessions – i.e. body size, lower body power and strength – are the same for the whole junior team.

This study is not without limits. It is important to notice that in the present study pp was computed indirectly using CMJh and body mass, while sprint momentum was computed as average over 10 m or 30 m. An estimate of CMJpp, in fact, has been shown not to be accurate when compared to force plate measurements (Tessier, Basset, Simoneau, & Teasdale, 2013). The insufficient measurement accuracy could have impacted on the logistic analysis results. Further studies should employ direct measurement of jump force or displacement and estimate power from force-time or position-time curves, employing force plates or linear position transducers, respectively (Cormie, McBride, & McCaulley, 2007).

2.5. CONCLUSIONS

In the present study, age, anthropometric and physical characteristics of talent identified U20 Italian rugby union players were analyzed. It was possible to assess position specific differences between BKS and FWS players in all the variables tested. Differences between internationally selected and non-selected players were present in body mass, CMJpp, 10mm, 30mm, SQ1RM, DL1RM, and BP1RM. Logistic regression analysis identified SQ1RM to be a significant predictor of selection. These results point out the importance of body size and strength for international selection at the U20 level, expanding the present literature. It is therefore possible to suggest to strength and conditioning coaches involved with the development of young rugby players to put the main emphasis of their training in increasing the athletes' size and maximal strength. Body mass accrual must favor the accumulation of lean body mass over fat mass.

3. STUDY 2

COMPARISON OF RESISTANCE TRAINING TO FAILURE TO NOT TO FAILURE IN

RUGBY UNION PLAYERS

3.1. INTRODUCTION

High levels of strength and power are critical towards success in Rugby (Cunningham et al., 2018). Players are required to perform dynamic activities (e.g. sprints, jumps, and changes of direction) and static exertions (scrum, ruck, mauls, and wrestle) during a match (Austin et al., 2011). For those latter activities, the players' size are crucial towards overcoming their opponents (D. J. Smart et al., 2013), as heavier players can carry larger inertia into a collision with their opponents. In fact, differences in size, strength, power and speed have been consistently reported among players of different competitive levels (Delahunt et al., 2013; Duthie et al., 2003; Geeson-Brown et al., 2020; Hansen et al., 2011; K. Quarrie et al., 1996). Furthermore, as resulted from the Study 1 in the present thesis, lower body maximal strength appears to be a crucial discriminating factor among young Italian national and international level players.

Resistance training (RT) is an exercise modality commonly employed by strength and conditioning coaches to achieve these desired anthropometric and physical characteristics (Deweese et al., 2016; DeWeese et al., 2015b; Schoenfeld, Grgic, et al., 2017; Suchomel et al., 2016). A popular modality to prescribe RT is the use of repetition maximum (RM), which consists in indicating an exact number or range for the repetitions to be completed and to achieve momentary muscle failure at that at the end of the set (FAIL) (Izquierdo et al., 2006). The use of RM in prescribing the load for RT exercises is not without shortcomings. Promoting consistent training to failure makes it difficult to manage accumulative fatigue as it is impossible to prescribe an exact load, and therefore workload for a given RT session (Izquierdo-Gabarren et al., 2010; Stone, Chandler, Conley, Kramer, & Stone, 1996). Still, FAIL have been amply reported to elicit positive adaptation in both muscle size (Willardson, Norton, & Wilson, 2010) and strength (Schoenfeld et al., 2014), and has been suggested as a method to prescribe RT also for rugby union players (Corcoran & Bird, 2009).

More recently, the practice of FAIL has been questioned in several studies which compared it to other prescription methods. Izquierdo and colleagues (Izquierdo et al., 2006), compared the effects of FAIL to training not to failure (NO-FAIL) in international level Basque Pelota players over a duration of 16 weeks. NO-FAIL was more beneficial for lower body maximal strength (smith machine half squat and bench press 1RM), and power, that was computed with an encoder attached at the end of the barbell during half squat and bench press warm up at 60% of 1RM. FAIL was also investigated in stronger individuals (K. M. Carroll, Bernards, et al., 2019). After 11 weeks of periodized training involving successive blocks targeting strength endurance, maximal strength, and speed-strength, lower improvements in vertical jump, rate of force development and maximal strength were observed in comparison to NO-FAIL.

The reduced efficacy of FAIL is possibly reliant upon delayed recovery timeframe following a RT session involving several sets carried to momentary muscle exhaustion (Morán-Navarro et al., 2017). Investigating the recovery time from a single session of SQ and BP, the Authors reported that NO-FAIL resulted in a considerably faster recovery of neuromuscular performance, in the range of 24 – 48 h in advance compared to FAIL. Prolonged recovery time are ascribable to increased accumulated fatigue (Nóbrega & Libardi, 2016). On the other hand, reducing the number of repetitions completed during each set at the same %1RM can increase movement speed and power generated (Pareja-Blanco, Sánchez-Medina, Suárez-Arrones, & González-Badillo, 2017) and would decrease accumulated fatigue and expedite recovery (K. M. Carroll, Bernards, et al., 2019).

In the literature, no information is present comparing FAIL and NO-FAIL in rugby union, or other large field invasion sports. The suggested superiority of training NO-FAIL would be exploited when training rugby players, with the objective of achieving superior size, strength and power. Furthermore, no study has evaluated the effects of FAIL or NO-FAIL on sprint and change of direction, two key skills for rugby players (Freitas et al., 2018).

Therefore, the aim of this study is to compare FAIL to NON-FAIL RT program on lower body measures of the muscle size, strength and power; and sprint and change of direction ability.

3.2. METHODS

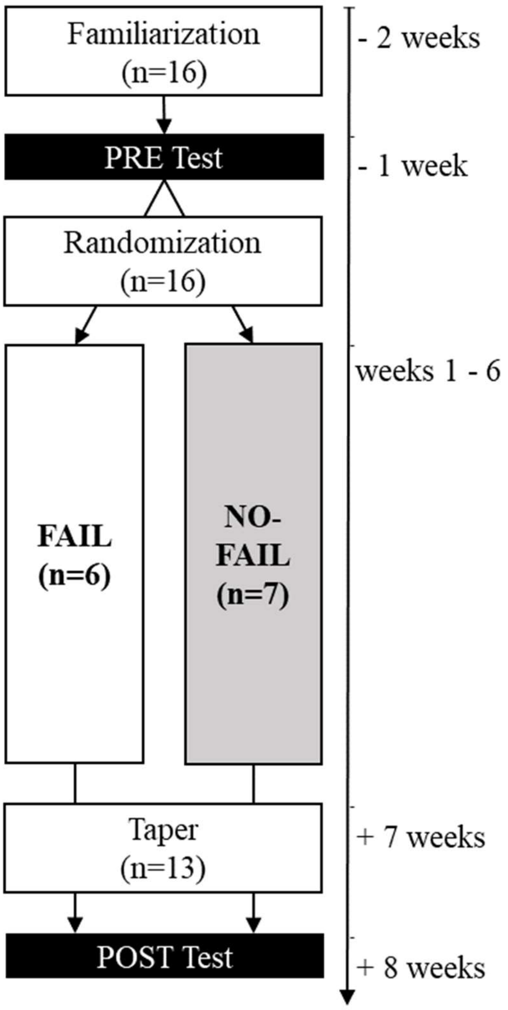
Subjects

Sixteen male rugby union players, all from the same club competing in the Italian Serie B championship (22.5 ± 2.9 yrs., 178.7 ± 7.6 cm, 87.7 ± 9.7 kg) were recruited. All players had a competitive playing age greater than three years. Due to injury, three players dropped out of the study, lowering the sample size to 13 subjects. The experimental protocol was approved by the Institutional Review Board of the University of Milan (2/12) in compliance with the Helsinki declaration. All players were informed of the risks and benefits of the investigation prior to obtaining signed consent.

Experimental approach

The study was conducted during the off-season and employed a randomized counterbalanced parallel-group design. Testing was conducted before (PRE) and one week following the end (POST) of the seven-week-long training intervention period. Players were familiarized during two training sessions with the testing procedures one week before PRE. After PRE testing, players were randomly allocated to either one of two counterbalanced groups: FAIL or NO-FAIL. Both groups completed three resistance training sessions, one sprint session, and two rugby practices per week. To assess the effects of the two different training protocols players underwent to two testing sessions during both PRE and POST. During the first testing session anthropometric, vertical jump, f-v profile, and maximal strength were assessed. 72 hours afterwards, during the second testing session, sprint and change of direction were assessed. A schematic representation of the experimental design is presented in Figure 3.1.

Figure 3.1 Study design diagram.



Notes: FAIL = training to failure group,
NO-FAIL = training not to failure group

Training

Squat (SQ) and Deadlift (DL) exercises were executed on the first and third weekly resistance training sessions, the exercise intensity relative to the one repetition maximum (%1RM) and the number of sets performed increased every two weeks. Both groups performed three sets at 75% on weeks one and two, four sets at 80% on weeks three and four, and five sets at 85% on weeks five and six. FAIL group carried each set prescribed to momentary muscle failure and athletes completed, on the first set, ten reps at 75%, eight reps at 80%, and six reps at 85%, respectively. On the sets following the first one, the number of repetitions completed decreased, always reaching muscle failure during each set. Players allocated to NO-FAIL, instead, completed only half of the of repetitions performed on the first set by players allocated to FAIL. Therefore, athletes in NO-FAIL performed sets of five reps at 75%, four reps at 80%, and three reps at 85% (Table 3.1). Additionally, athletes allotted to both NO-FAIL and FAIL groups performed three times a week four upper body exercises, the upper body RT program was identical for the two groups (Table 3.2). During week seven a taper was provided in the form of training cessation (Travis, Mujika, Gentles, Stone, & Bazyler, 2020), removing all lower body resistance training exercises.

Table 3.1 Resistance training program for squat and deadlift exercises.

	Repetitions (n)		Sets (n)	Intensity (%1RM)	
	FAIL	NO-FAIL		day 1	day 3
Week 1	max (~10)	5	3	75%	70%
Week 2	max (~10)	5	3	75%	70%
Week 3	max (~8)	4	4	80%	75%
Week 4	max (~8)	4	4	80%	75%
Week 5	max (~6)	3	5	85%	80%
Week 6	max (~6)	3	5	85%	80%
Week 7	–	–	–	–	–

Notes: FAIL = training to failure group, NO-FAIL = training not to failure group, 1RM = one repetition max, in parenthesis the approximate number of repetitions completed in the first set.

Table 3.2 Resistance training program for upper body exercises.

	Sets (n)	Repetitions (n)	Intensity (%1RM)		
			day 1	day 2	day 3
			BP, OHP, SR, ARO#	BP, OHP, SR, PLP§	BP, OHP, SR, SU#
Week 1	6	6	65%	62.5%	60%
Week 2	6	6	67.5%	65%	62.5%
Week 3	6	6	70%	67.5%	65%
Week 4	3	6	65%	62.5%	60%
Week 5	5	5	72.5%	70%	67.5%
Week 6	5	5	75%	72.5%	80%
Week 7	5	5	77.5%	–	72.5%

Notes: FAIL = training to failure group, NO-FAIL = training not to failure group, 1RM = one repetition max, BP = bench press, OHP = overhead press, SR = seal row, ARO = abdominal roll-out, PLP = prone lat pulldown, SU = sit ups, # = performed 3 sets of 12 reps Week 1 – 6, § = performed 4 sets of 8 reps Week 1 – 6.

The weekly sprint training session was completed on an outdoor natural grass turf and consisted of four 10 m sprints, three 20 m sprints, and two 30 m sprints, with one minute, two minutes and three minutes recovery, respectively.

During the training intervention, volume load (load x number of repetitions performed) was recorded for each training session (Hornsby et al., 2018).

Procedures

Anthropometric

Height and body-mass were assessed with a digital scale and a stadiometer at the nearest 0.1 kg and 0.1 cm. Lower body measures of muscle size were assessed through measurement of midthigh circumference, and anterior midthigh skinfold, the athletes were measured while sitting with a tape measure and skinfold caliper, respectively. Using the equations by Housh et al. (Housh et al., 1995) it was possible to estimate quadriceps cross sectional area (QuadCSA) and hamstrings cross sectional area (HamCSA):

$$QuadCSA = 2.52 \cdot midthigh\ circumference\ (cm) - 1.25 \cdot anterior\ midthigh\ skinfold\ (mm) - 45.13$$

$$HamCSA = 1.08 \cdot midthigh\ circumference\ (cm) - 0.64 \cdot anterior\ midthigh\ skinfold\ (mm) - 22.69$$

Every measurement was taken twice and the mean of the two measurement was used for further procedures.

Vertical Jump

Players' vertical jump ability was assessed through countermovement jump test (CMJ) and the countermovement jump test with arm swing (CMJA). The CMJ was performed with players holding a pvc pipe on the top of their shoulders, resting on the prominent portion of the 7th cervical vertebra. Players were instructed to jump, after a countdown, at the operator's signal to jump. The verbal directions given by the operator were "three, two, one, jump!". Players performed two CMJ warm-up jumps at 50% and 75% of their subjectively perceived maximal effort, respectively. Players then performed at least two CMJ at the best of their perceived effort. Players performed one CMJA warm-up jump at 75% of their subjectively perceived maximal effort. P layer then performed at least two CMJA at the best of their perceived effort. A 60 s recovery period was conceded between attempts.

Players were verbally strongly encouraged by the operator to jump the highest possible. If the player landed with bent lower limbs, the attempt was discarded, and he was asked to perform an additional jump. If the player improved his jump height by more than 2 cm, an additional jump was performed.

Jump height (h) was assessed using an optoelectrical system composed of two one m long bars (Optojump Next, Microgate, Bolzano, Italy) (Glatthorn et al., 2011). The h was computed from flight times (Lees & Fahmi, 1994). Peak power (pp, in W) was computed from h and body-mass (Evertett A. Harman et al., 1991).

For statistical analysis purposes the average of the two best measurements was considered.

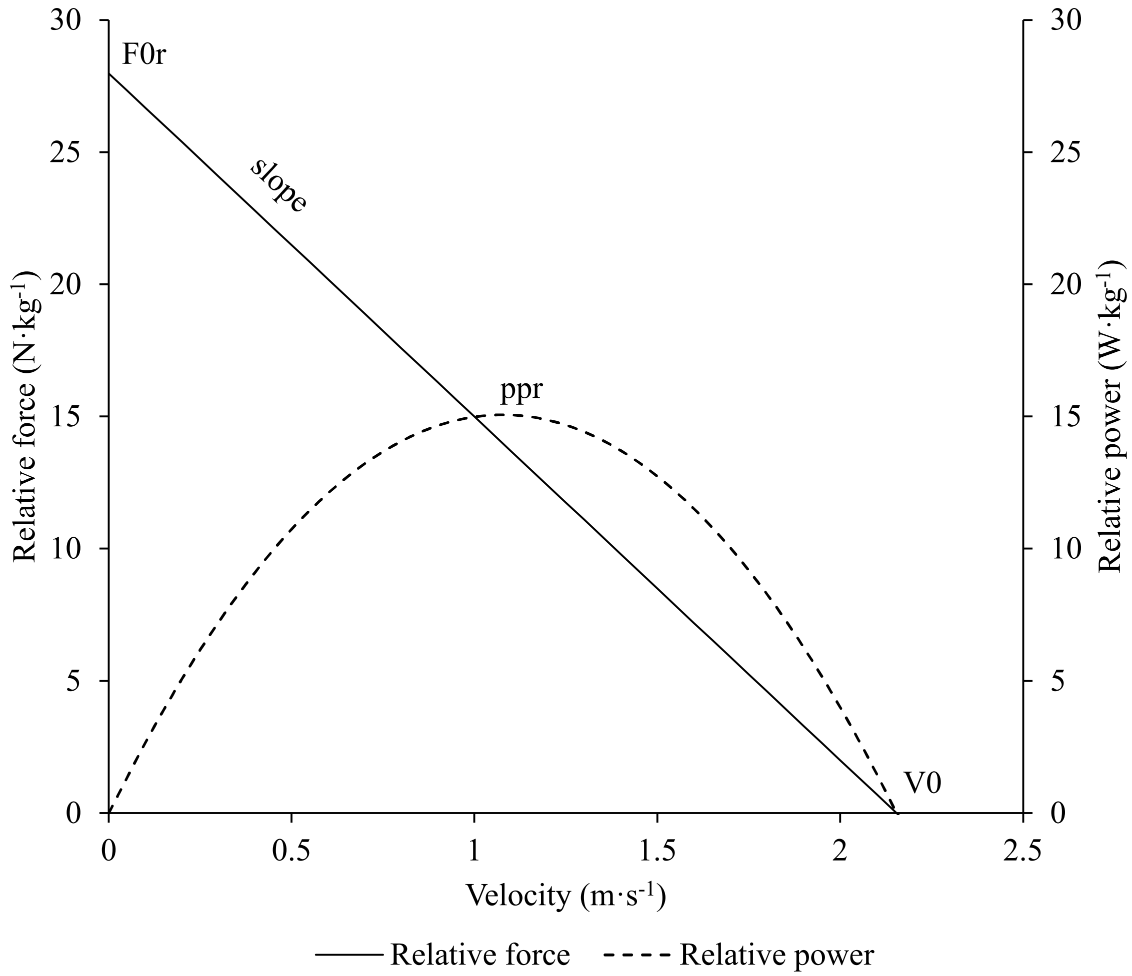
Force – Velocity Profile

Lower body force-velocity profile was assessed in the back squat (SQ) exercise (Bosco et al., 1995; Samozino, Morin, Hintzy, & Belli, 2008). Athletes completed sets of two reps at four incremental overloads corresponding to 20%, 40%, 60%, and 80% of the previously estimated 1RM. The average velocity of the barbell was recorded by a linear encoder (Chronojump, Barcelona, Spain) (Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca, & García-Ramos, 2019; Timon et al., 2019) applied to one end of the barbell. For each overload average force output was computed by the Chronojump software (v 1.8.1) (Illera-Domínguez et al., 2018). Average relative force computation accounted for the acceleration imparted by the athlete to the barbell (Cormie et al., 2007). From individual velocity and force data – expressed relatively to each player's body mass – at each overload it was possible to compute the linear f-v relationship, using the least squares method. The maximal theoretical velocity (V0, $m\cdot s^{-1}$) and the maximal theoretical relative force (F0r, $N\cdot kg^{-1}$) were extrapolated from the f-v relationship (Figure 3.2), as the relationship intercepts with the vertical axis and the horizontal axis, respectively. Additionally, the slope of the relationship was computed (SQslope, $N\cdot s\cdot m^{-1}\cdot kg^{-1}$). The peak power relative to body mass (SQppr, $W\cdot kg^{-1}$) was calculated via the formula previously validated (Samozino, Rejc, Di Prampero, Belli, & Morin, 2012):

$$SQppr = \frac{F0r \cdot V0}{4}$$

For statistical analysis purposes the average of the two measurements was considered.

Figure 3.2 Force-velocity profile for a player in the back squat.



Notes: F0r = maximal theorethical relative force for the relationship; V0 = maximal theorethical velocity for the relationship; slope = slope of the f-v relationship; ppr = peak power computed from the f-v relationship.

Maximal Strength

Subjects' maximal dynamic strength was assessed through a 1RM test in the SQ and deadlift (DL) exercises. Players could wear a weightlifting belt during testing but no knee or elbow wraps nor lifting straps were conceded. The protocol used to assess the 1RM was standardized following NSCA guidelines (Haff & Triplett, 2015). Testing was supervised by experienced strength and conditioning coaches. SQ was deemed valid if the player could squat to parallel (hip crease below upper part of the patella) (SQ1RM). DL was deemed valid if the player could stand and fully extend knee and hip joints (DL1RM).

Sprint and change of direction

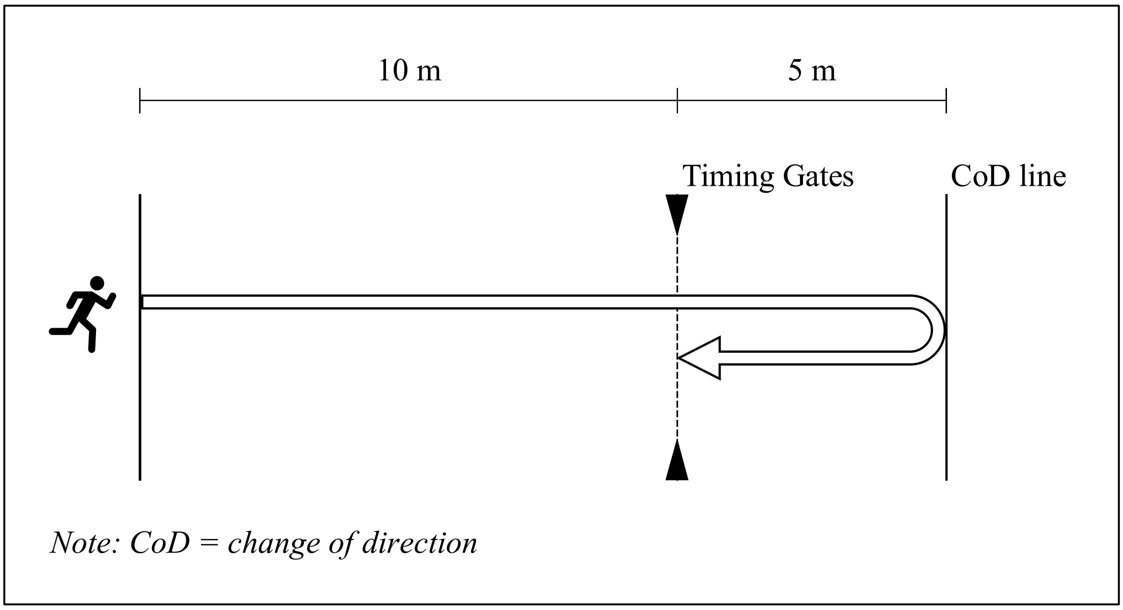
The subjects underwent to inline sprint and change of direction speed testing on a natural grass turf. Players performed an extensive warm up before the test, comprising five min low intensity aerobic activity (jog), 10 min dynamic stretching exercises involving the muscles of the legs, thighs, hips and trunk, and five min sprint drills (skipping and strides) performed over 20 m. Then, players performed two 10 m warm-up sprints, the first one at 50% and the second one at 75% of their subjectively perceived maximal effort, respectively.

Players performed two sprints over 10 m and then two sprints over 30 m (Green, Blake, & Caulfield, 2011). Four min recovery was allowed between trials. Players placed the foremost foot 0.3 m behind the starting line and started the sprint after the operator command "Go". The players were verbally incited by the operator to sprint as fast as they could. Sprint times (t) were collected using optoelectrical gates (Witty, Microgate, Bolzano, Italy) positioned at the starting line (height set at 0.3 m) and the finish line, either 10 m or 30 m line (height set at 1.0 m). Additionally, momentum ($kg \cdot m \cdot s^{-1}$) was computed for 10 m (10mm) and 30 m (30mm) sprints using the equations by Barr and colleagues (Barr et al., 2014).

For assessing change of direction speed, the 5-0-5 change of direction test was performed (CoD505) (J A Delaney et al., 2015). The players sprinted from a marker set at 15 m from the change of direction line, crossing a timing gate set at five-meter distance from the change of direction line, starting the timer. When the athletes reached the change of direction line, they performed a 180° change of direction and sprinted back, crossing again the timing gate set at 5 m the line and stopping the timer

(Figure 3.3). Subjects performed two warm up sprints at 50% and 75% of their subjectively perceived maximal effort, followed by two trials at maximal effort. Players were conceded three min recovery period between trials.

Figure 3.3 Layout for 5-0-5 change of direction test.



For statistical analysis purposes the average of the two best times was considered.

Statistical analysis

Data is shown as mean ± standard deviation. Normal distribution of the data was tested with the Shapiro-Wilk test. The level of statistical significance alpha was set at 0.05. Reliability of the measurements was quantified by a two-way mixed intraclass correlation coefficient (ICC) for average measurements (ICC type 3, k) and standard error of measurement (SEM = standard deviation · √ (1 – ICC)).

To assess potential differences in volume load between groups an unpaired Student's T-test was performed.

Multiple ANOVA mixed model tests were employed for each dependent variable. TIME (PRE/POST) was the within-subjects factor, GROUP (FAIL/NO-FAIL) the between-subjects factor.

In case of significant interaction, pairwise comparisons have been completed using Sheffe adjustment.

Furthermore, between-groups effect sizes using Hedge's *g* (ES = [(POST NO-FAIL – PRE NO-FAIL) – (POST FAIL– PRE FAIL)]/pooled standard deviation) were computed. ES magnitude was assessed with the following criteria: trivial<0.2, small<0.5, medium<0.8, large>0.8. Unpaired Student's T-test was conducted on volume load.

To compare the effectiveness of the two training interventions, the ratio of the raw change score for each variable and the accrued volume load were tested using Mann Whitney non-parametric tests, due violations to hypothesis of normality of the distribution.

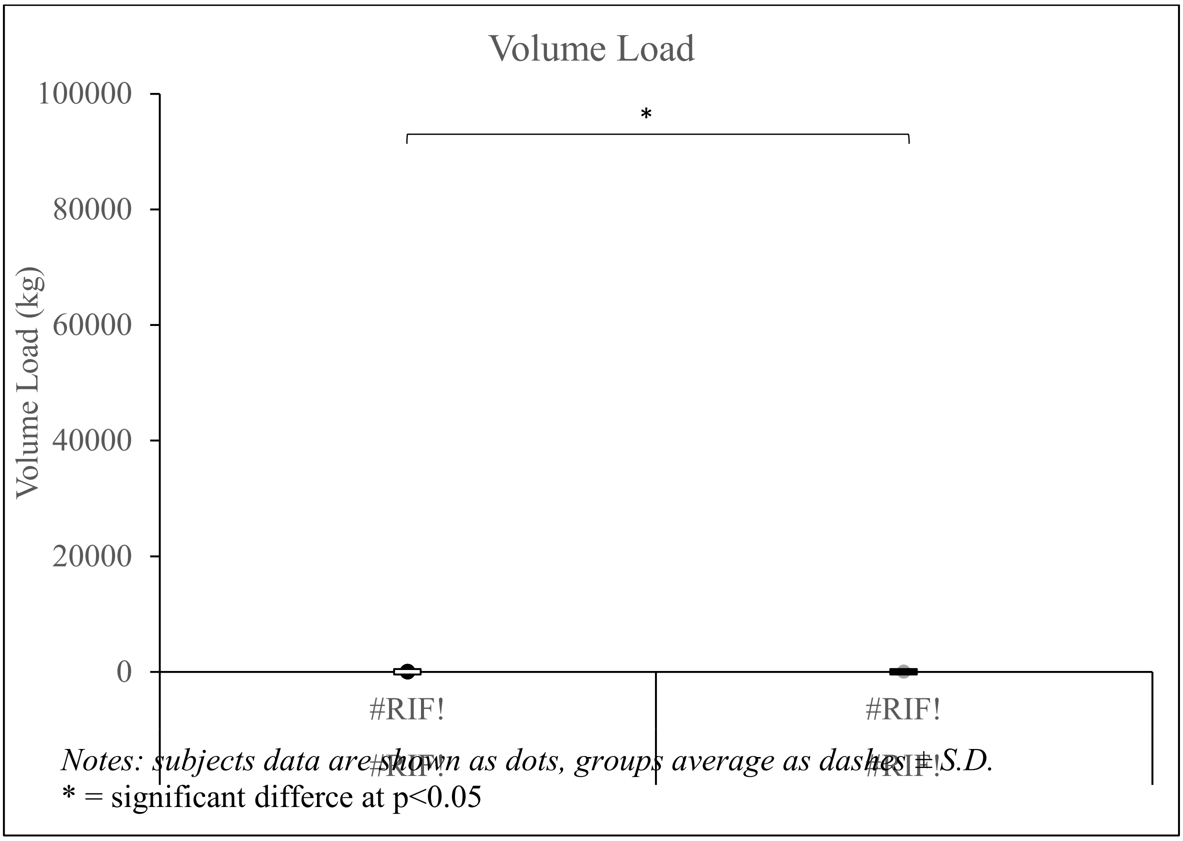
All analyses were conducted using SPSS 21 (IBM, Chicago, USA) and filtered into a customized spreadsheet (Excel, Microsoft, Redmond, USA).

3.3. RESULTS

T-test

The volume resulted significantly higher for FAIL compared to NO-FAIL (T(11)=10.37, p<0.001) (Figure 3.4).

Figure 3.4 Graph for back squat and deadlift volume load.



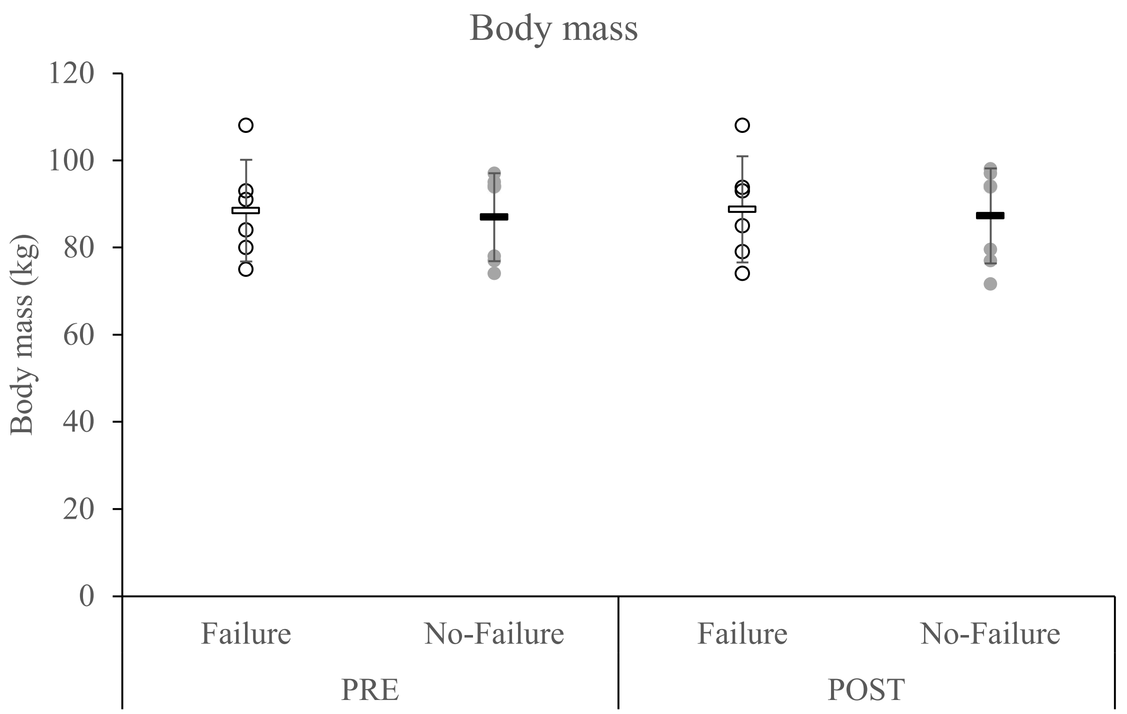
ANOVA

Anthropometric

ICC resulted 0.973 for QuadCSA (SEM = 1.23 cm^2) and 0.967 for HamCSA (SEM = 0.73 cm^2).

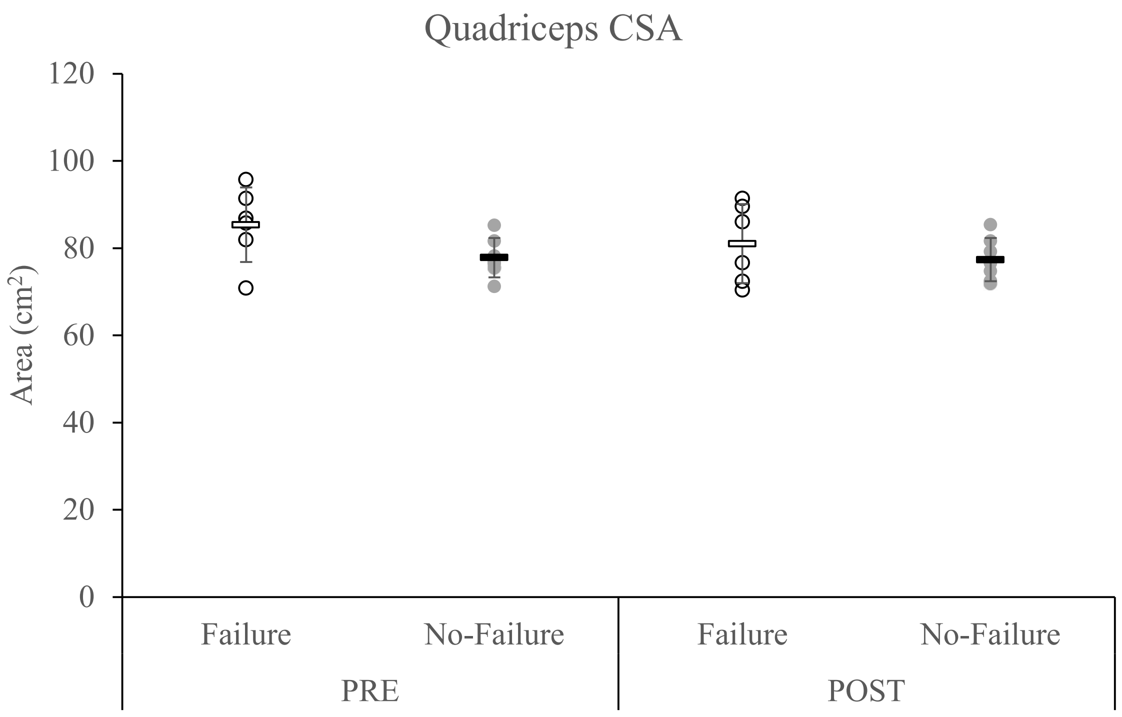
Body mass displayed no interaction effect (F(1,11)=0.000, p=1.000), no effect for time (F(1,11)=0.564, p=0.468) and no effect for group (F(1,11)=0.058, p=0.813) (Figure 3.5). QuadCSA displayed no interaction effect (F(1,11)=2.436, p=0.147), no effect for time (F(1,11)=3.761, p=0.079) and no effect for group (F(1,11)=2.373, p=0.152) (Figure 3.6). HamCSA displayed no interaction effect ($F(1,11)=2.523$, $p=0.14$), no effect for time ($F(1,11)=3.788$, $p=0.078$) and no effect for group ($F(1,11)=2.437$, $p=0.147$) (Figure 3.7).

Figure 3.5 Bar graph for body mass.



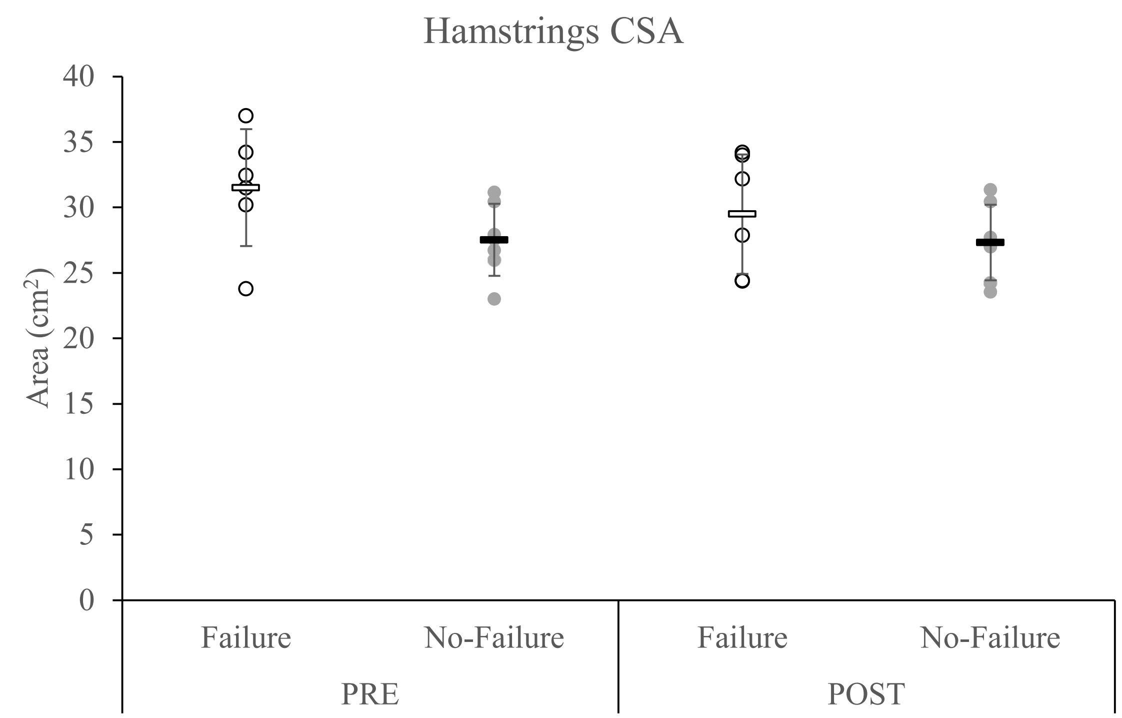
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.6 Bar graph for quadriceps cross sectional area (CSA).



Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.7 Bar graph for hamstrings cross sectional area (CSA).



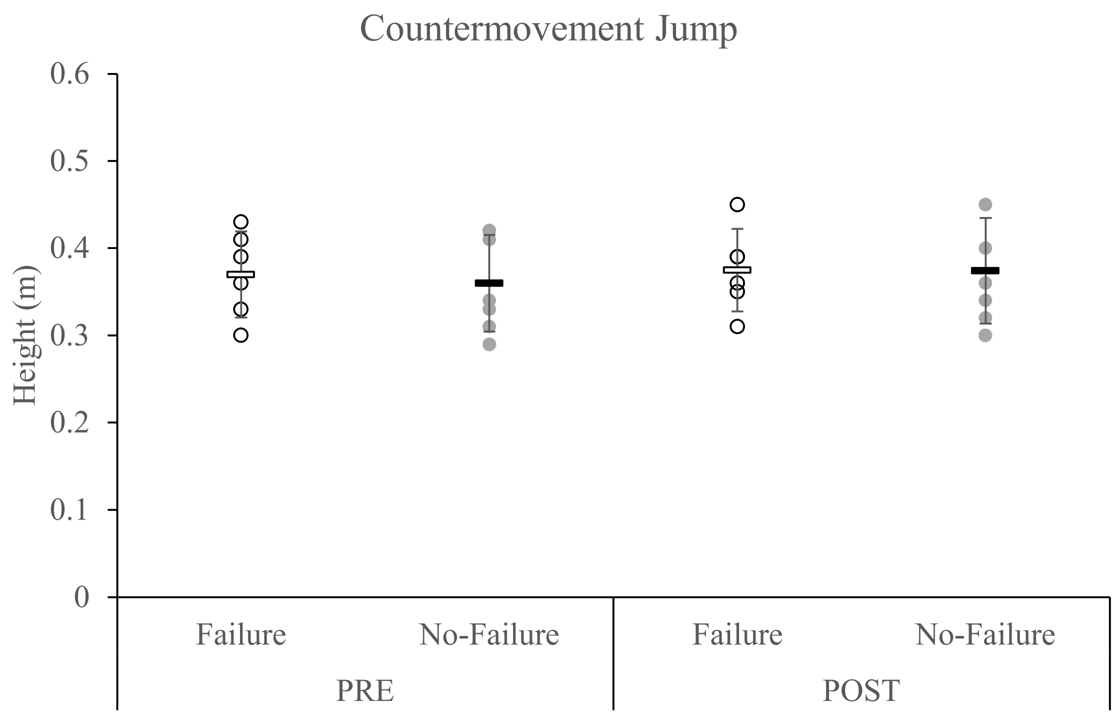
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Vertical Jump

ICC resulted 0.968 for CMJh (SEM = 0.009 m), 0.992 for CMJAh (SEM = 0.006 m), 1.00 for CMJppr (SEM = 0.00 W) and 0.1 for CMJAppr (SEM = 0 W).

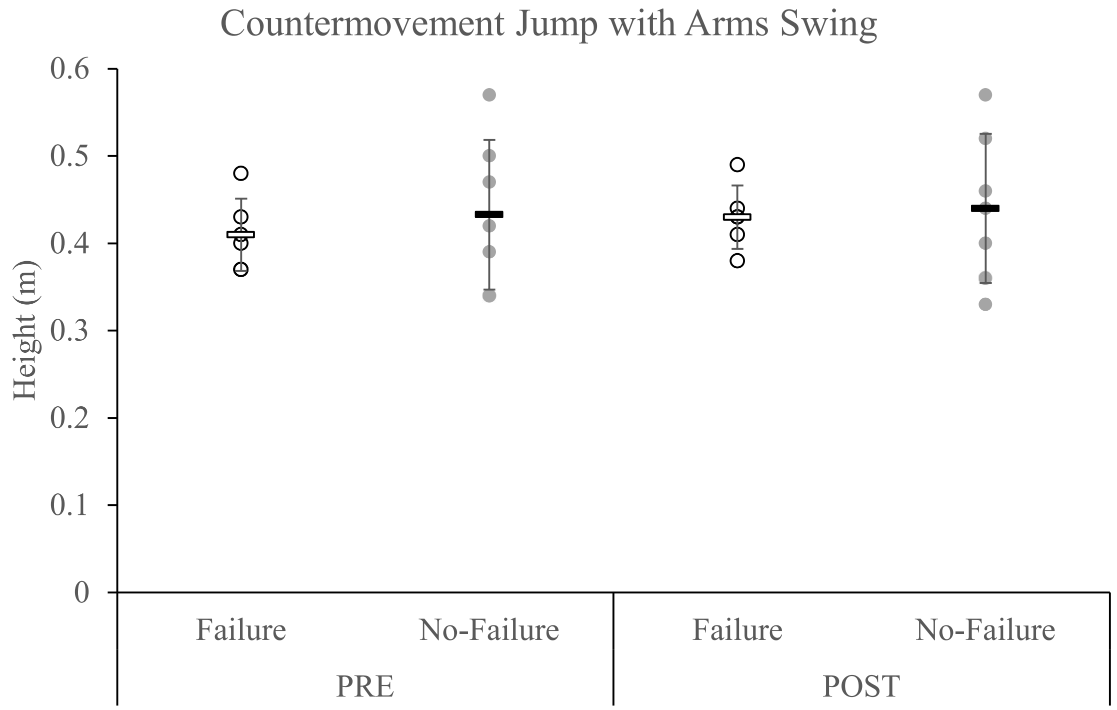
CMJh displayed no interaction effect ($F(1,11)=0.536$, $p=0.480$), no effect for time ($F(1,11)=2.31$, $p=0.157$) and no effect for group ($F(1,11)=0.034$, $p=0.858$) (Figure 3.8). CMJAh displayed no interaction effect ($F(1,11)=1.06$, $p=0.325$), no effect for time ($F(1,11)=4.724$, $p=0.052$) and no effect for group ($F(1,11)=0.192$, $p=0.67$) (Figure 3.9). CMJppr displayed no interaction effect ($F(1,11)=0$, $p=0.984$), no effect for time ($F(1,11)=0.622$, $p=0.447$) and no effect for group ($F(1,11)=0.06$, $p=0.812$) (Figure 3.10). CMJAppr displayed no interaction effect ($F(1,11)=0.001$, $p=0.979$), no effect for time ($F(1,11)=0.646$, $p=0.439$) and no effect for group ($F(1,11)=0.057$, $p=0.816$) (Figure 3.11).

Figure 3.8 Bar graph for countermovement jump height.



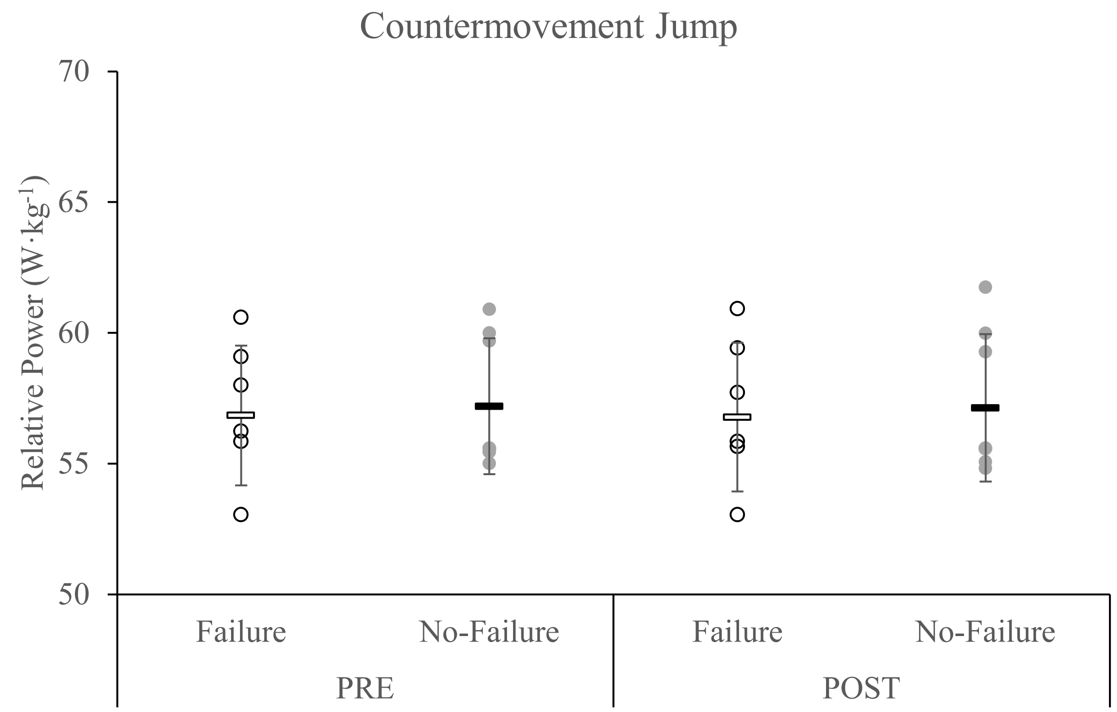
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.9 Bar graph for countermovement jump with arm swing height.



Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.10 Bar graph for countermovement jump peak power.



Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.11 Bar graph for countermovement jump height with arm swing peak power.

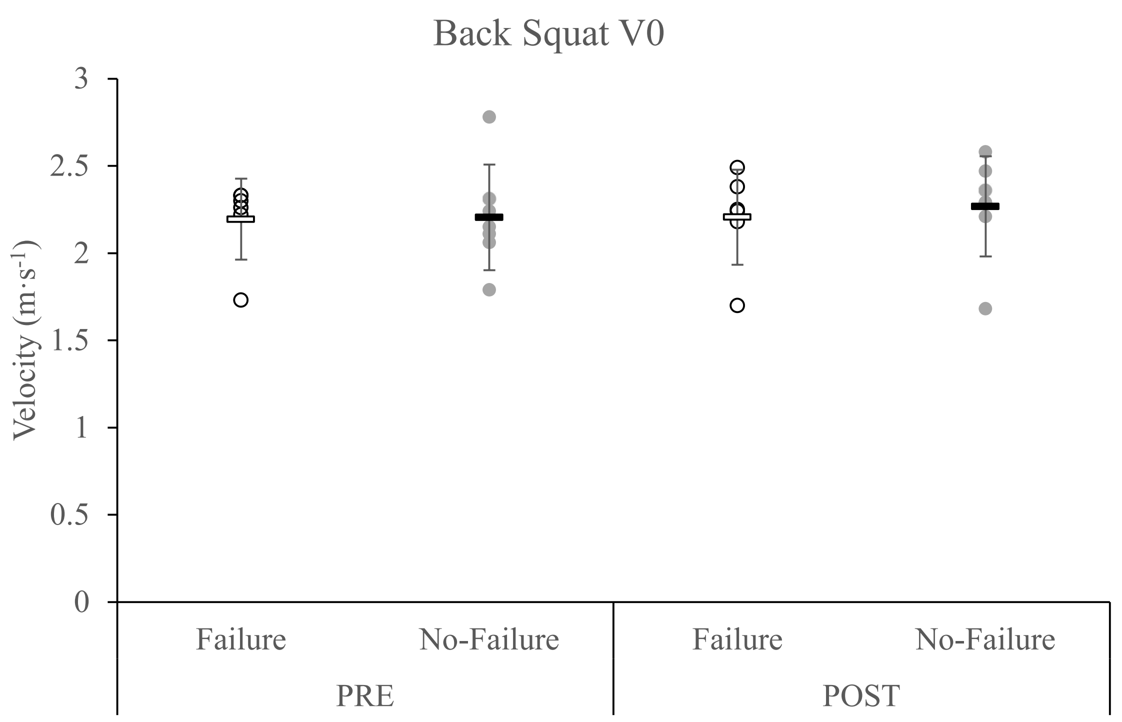
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Force-velocity profile

ICC resulted 0.927 for SQV0 (SEM = 0.07 m·s^{-1}), 0.880 for SQF0r (SEM = 0.79 N), 0.921 for SQslope (SEM = 0.71 N·s·m^{-1}·kg^{-1}) and 0.961 for SQppr (SEM = 0.25 W·kg^{-1}).

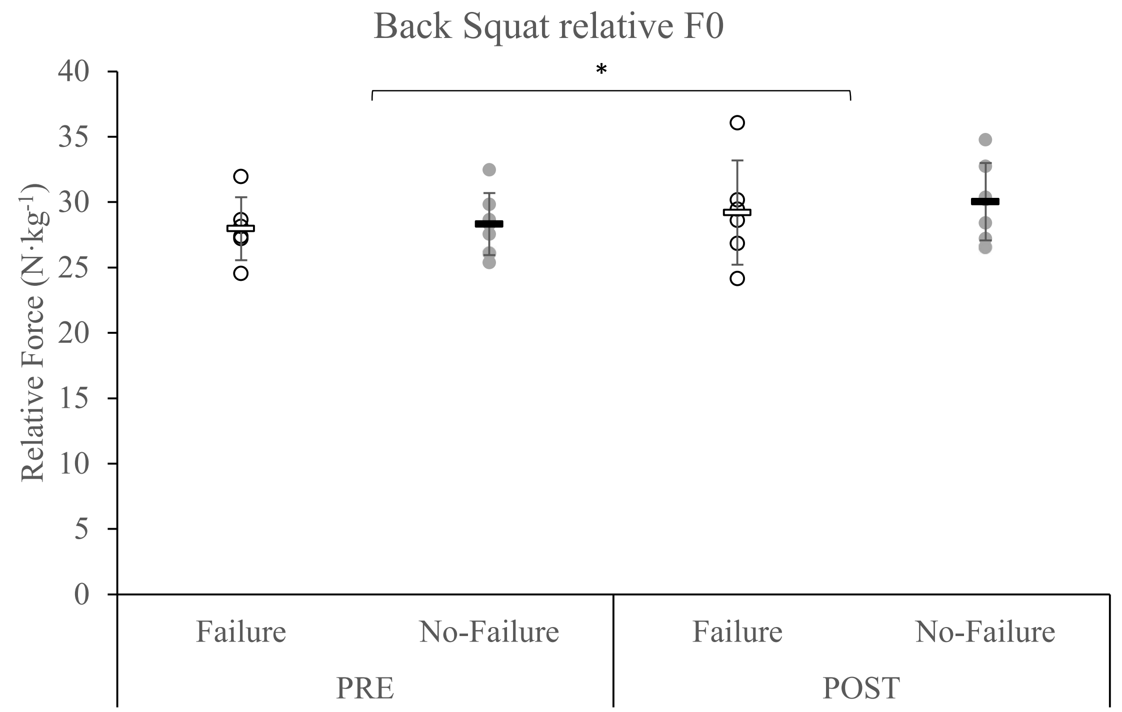
SQV0 displayed no interaction effect ($F(1,11)=0.394$, $p=0.543$), no effect for time ($F(1,11)=0.835$, $p=0.38$) and no effect for group ($F(1,11)=0.060$, $p=0.811$) (Figure 3.12). SQF0r displayed no interaction effect ($F(1,11)=0.255$, $p=0.623$), a significant effect for time ($F(1,11)=9.489$, $p=0.01$) and no effect for group ($F(1,11)=0.134$, $p=0.721$) (Figure 3.13). SQslope displayed no interaction effect ($F(1,11)=0.033$, $p=0.859$), no effect for time ($F(1,11)=1.62$, $p=0.229$) and no effect for group ($F(1,11)=0.001$, $p=0.983$) (Figure 3.14). SQppr displayed no interaction effect ($F(1,11)=1.948$, $p=0.190$), a significant effect for time ($F(1,11)=14.307$, $p=0.003$) and no effect for group ($F(1,11)=0.862$, $p=0.373$) (Figure 3.15).

Figure 3.12 Graph for maximal theoretical velocity of the force-velocity profile (V0) in the squat.



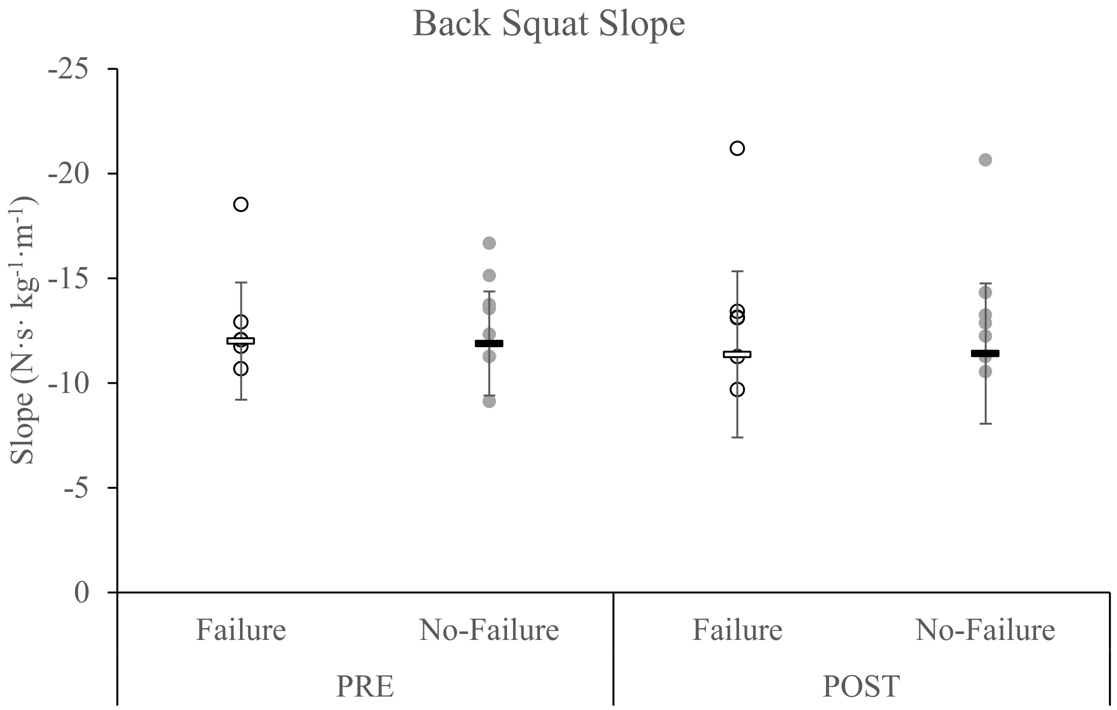
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.13 Graph for maximal theoretical relative force of the force-velocity profile (F0r) in squat.



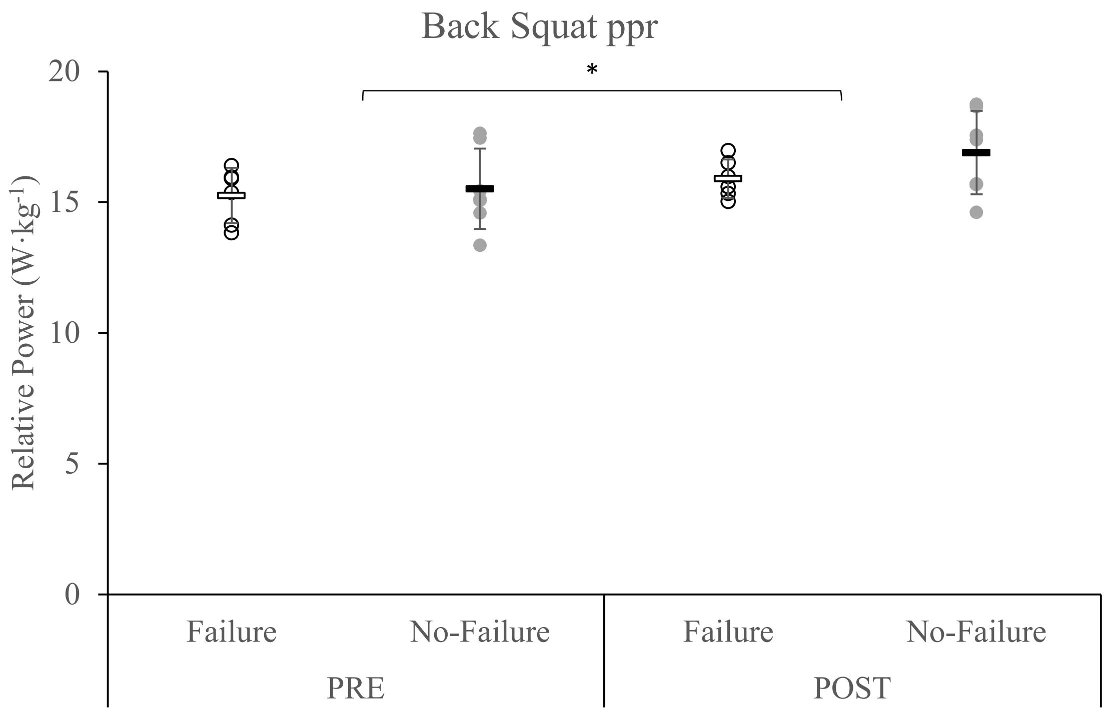
Notes: subjects data are shown as dots, groups average as dashes ± S.D.
** = signficant effect for time at p<0.05*

Figure 3.14 Graph for the slope of the force-velocity profile in the back squat.



Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.15 Graph for the relative peak power computed on the force-velocity profile in the squat.

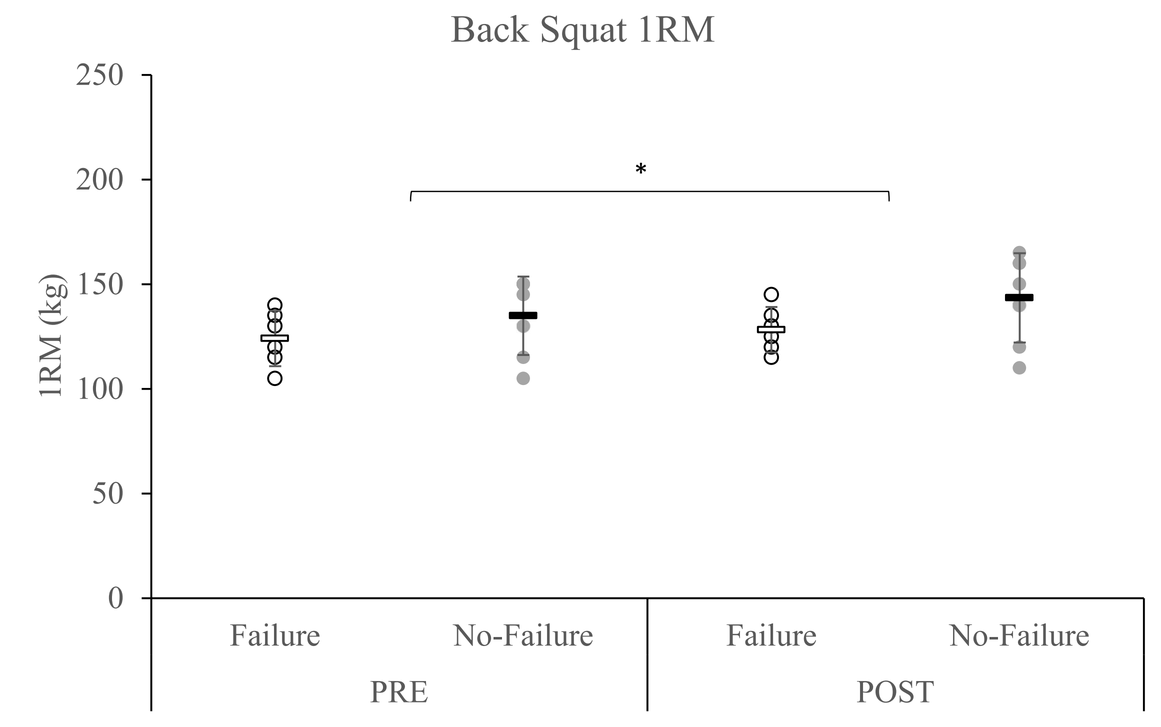


Notes: subjects data are shown as dots, groups average as dashes ± S.D.
* = signficant effect for time at $p<0.05$

Maximal strength

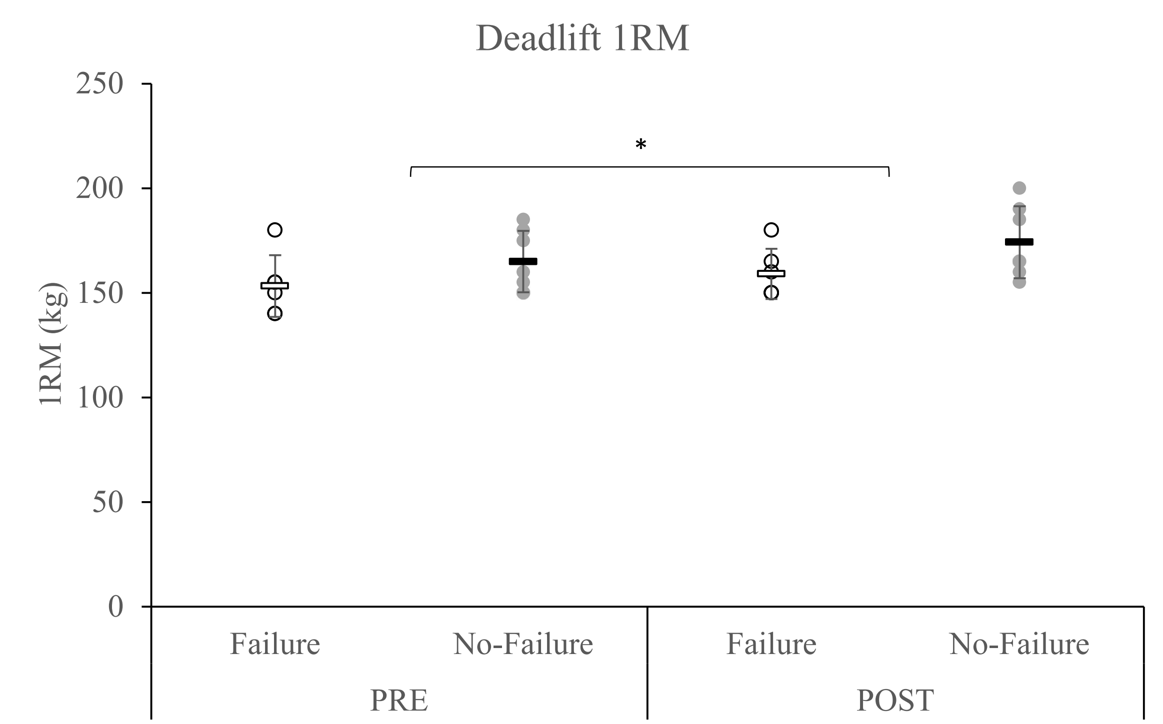
SQ1RM displayed no interaction effect (F(1,11)=1.934, p=0.192), a significant effect for time (F(1,11)=16.173, p=0.002) and no effect for group (F(1,11)=1.976, p=0.187) (Figure 3.16). DL1RM displayed no interaction effect (F(1,11)=0.781, p=0.396), a significant effect for time (F(1,11)=14.981, p=0.003) and no effect for group (F(1,11)=2.769, p=0.124) (Figure 3.17).

Figure 3.16 Graph for the back squat one repetition max (1RM).



Notes: subjects data are shown as dots, groups average as dashes ± S.D.
** = signficant effect for time at p<0.05*

Figure 3.17 Graph for the deadlift one repetition max (1RM).



Notes: subjects data are shown as dots, groups average as dashes ± S.D.
** = signficant effect for time at p<0.05*

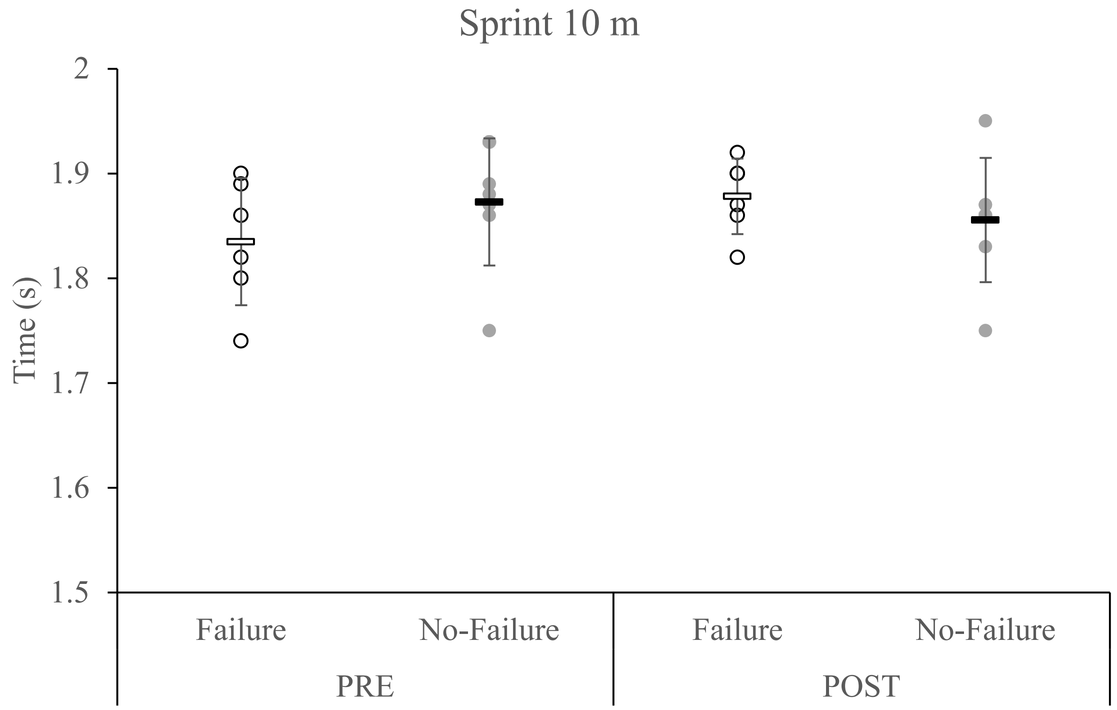
Sprint and change of direction

ICC resulted 0.891 for 10t (SEM = 0.02 s), 0.960 for 30t (SEM = 0.04 s), 0.979 for 10mm (SEM = 7.33 N·kg), 0.986 for 30mm (SEM = 6.84 N·kg) and 0.875 for CoD505 (SEM = 0.04 s).

10t displayed no interaction effect (F(1,11)=2.896, p=0.117), no effect for time (F(1,11)=0.543, p=0.477) and no effect for group (F(1,11)=0.09, p=0.769) (Figure 3.18). 30t displayed no interaction effect (F(1,11)=1.199, p=0.297), no effect for time (F(1,11)=3.511, p=0.088) and no effect for group (F(1,11)=0.289, p=0.602) (Figure 3.19). 10mm displayed no interaction effect (F(1,11)=2.004, p=0.185), no effect for time (F(1,11)=0.042, p=0.841) and no effect for group (F(1,11)=0.109, p=0.748) (Figure 3.20). 30mm displayed no interaction effect (F(1,11)=0.716, p=0.416), no effect for time (F(1,11)=0.992, p=0.341) and no effect for group (F(1,11)=0.014, p=0.907) (Figure 3.21).

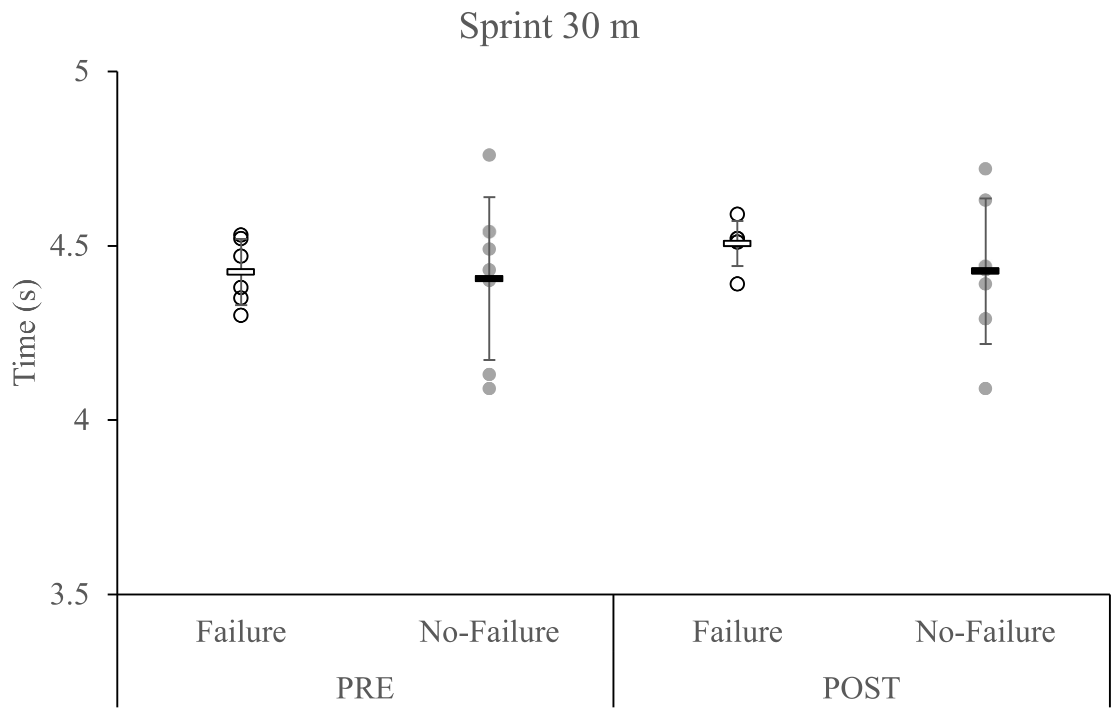
CoD505 displayed no interaction effect (F(1,11)=0.277, p=0.609), a significant effect for time (F(1,11)=14.658, p=0.003) and no effect for group (F(1,11)=0.767, p=0.400) (Figure 3.22).

Figure 3.18 Graph for 10 m sprint time.



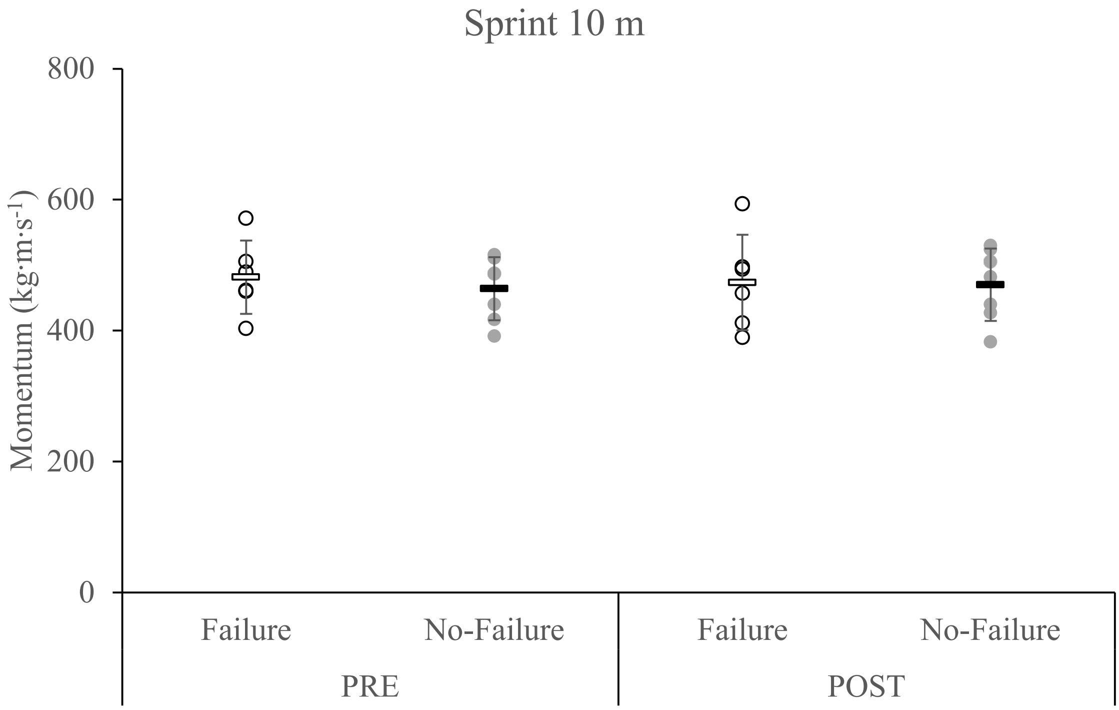
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.19 Graph for 30 m sprint time.



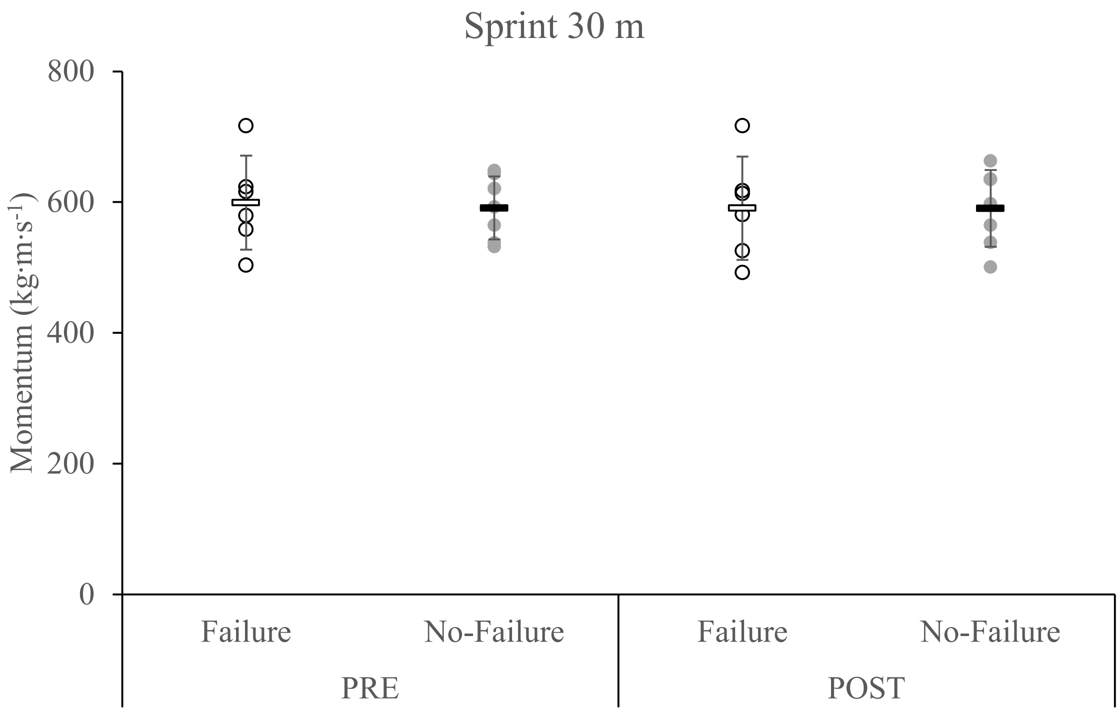
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.20 Bar graph for 10 m sprint momentum.



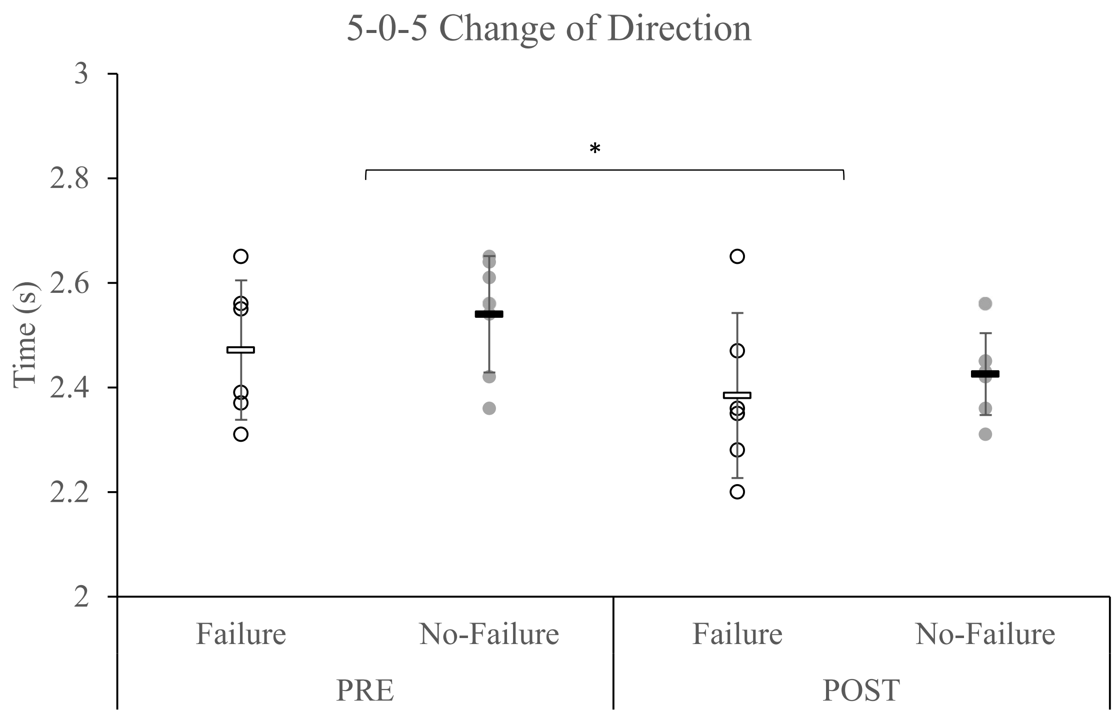
Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.21 Graph for 30 m sprint momentum.



Notes: subjects data are shown as dots, groups average as dashes ± S.D.

Figure 3.22 Graph for the 5-0-5 change of direction test time.



Notes: subjects data are shown as dots, groups average as dashes ± S.D.
** = signficant effect for time at p<0.05*

Effect Size

The between groups ES for body mass resulted null, for QuadCSA resulted large in favor of NO-FAIL, for HamCSA resulted large in favor of NO-FAIL.

The between groups ES for CMJh resulted small in favor of NO-FAIL, for CMJAh resulted medium in favor of FAIL, for CMJppr resulted medium, for CMJAppr resulted null.

The between groups ES for SQV0 resulted small in favor of NO-FAIL, for SQF0r resulted small in favor of NO-FAIL, for SQslope resulted null, for SQppr resulted medium in favor of NO-FAIL.

The between groups ES for SQ1RM resulted medium in favor of NO-FAIL, for DL1RM resulted medium in favor of NO-FAIL.

The between groups ES for 10t resulted large in favor of NO-FAIL, for 30t resulted medium in favor of NO-FAIL, for 10mm resulted medium in favor of NO-FAIL, for 30mm resulted medium in favor of NO-FAIL.

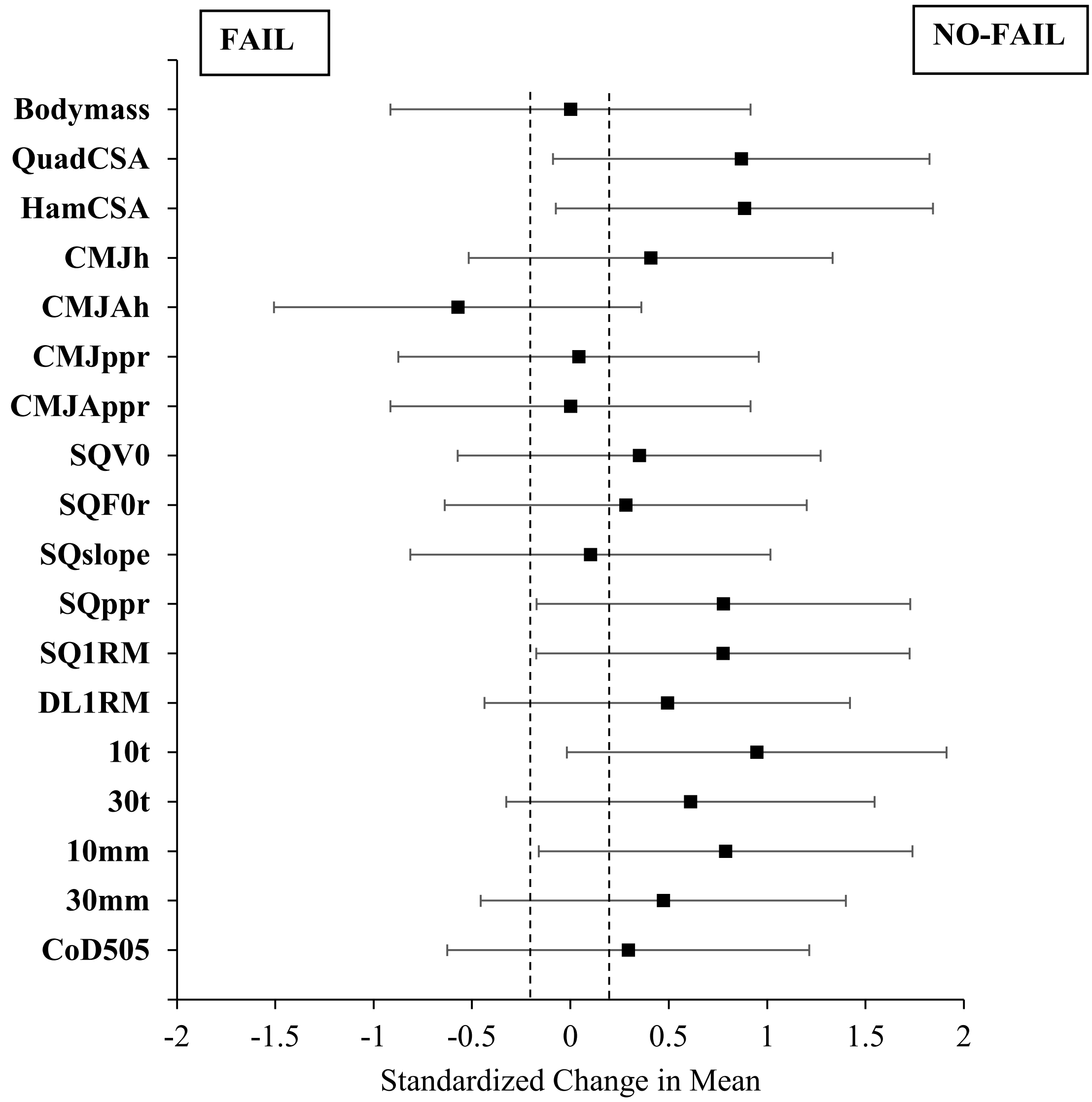
The between groups ES for CoD505 resulted small in favor of NO-FAIL.

ESs and the corresponding 90% confidence intervals are reported in Figure 3.23.

Mann-Whitney

Analyzing the ratio between the raw change and the total volume load, no statistically significant differences were present for body mass ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=18.0$, $z=-0.441$, $p=0.659$), QuadCSA ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=13.5$, $z=-1.073$, $p=0.283$), HamCSA ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=13.5$, $z=-1.073$, $p=0.283$), CMJh ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=12.0$, $z=-1.287$, $p=0.198$), CMJAh ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=9$, $z=-0.286$, $p=0.775$), CMJppr ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=19.0$, $z=-0.286$, $p=0.775$), CMJAppr ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=16.0$, $z=-0.741$, $p=0.475$), SQV0 ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=15.0$, $z=-0.857$, $p=0.391$), SQF0r ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=14.0$, $z=-1.000$, $p=0.317$), and SQslope ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=17.0$, $z=-0.571$, $p=0.568$). SQppr ratio for NO-FAIL (median=0.025 $W\cdot kg^{-1}\cdot ton^{-1}$) was higher than FAIL (median=0.010 $W\cdot kg^{-1}\cdot ton^{-1}$) ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=7.0$, $z=-2.000$, $p=0.046$). SQ1RM ratio for NO-FAIL (median=0.19 $kg\cdot ton^{-1}$) was higher than FAIL (median=0.07 $kg\cdot ton^{-1}$) ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=6.0$, $z=-2.143$, $p=0.032$). No statistically significant differences were present for DL1RM ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=14.0$, $z=-1.006$, $p=0.315$), 10t ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=10.0$, $z=-1.571$, $p=0.116$), for 30t ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=14.5$, $z=-0.930$, $p=0.199$), 10mm ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=12.0$, $z=-1.283$, $p=0.199$), 30mm ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=13.5$, $z=-1.073$, $p=0.283$), and CoD505 ($U(N_{FAIL}=6, N_{NO\text{-}FAIL}=7)=15.0$, $z=-0.862$, $p=0.389$).

Figure 3.23 Forest plot for the dependent variables.



Notes: Data is shown as effect size ± 90% confidence intervals. A shift to the left denotes a move favorable outcome for the training to failure group (FAIL) over training not to failure group (NO-FAIL). A shift to the right denotes a more favorable outcome for NO-FAIL over FAIL. QuadCSA = quadricep cross sectional area, HamCSA = hamstrings cross sectional area, CMJh = countermovemnt jump height, CMJAh = countermovement jump with arm swing height, CMJppr = countermovent jump relative peak power, CMJAppr = countermovement jump with arms swing relative peak power, SQV0 = maximal theorethical velocity in the back squat, SQF0r = maximal theoretical relative force in the back squat, SQslope = slope of the force-velocity profile in the back squat, SQppr = peak power computed for the force-velocity profile in the back squat relative to body mass, SQ1RM = back squat one repetition max, DL1RM = deadlift one repetition max, 10t = 10 m sprint time, 30t = 30 m sprint time, 10mm = 10 m sprint momentum, 30mm = 30 m sprint momenutm, CoD505 = 5-0-5 change of direction test time.

3.4. DISCUSSION

The main finding from this study is that, despite the lack of significant differences for any of the dependent variables between FAIL and NO-FAIL groups, ES analysis shows how NO-FAIL RT conveyed superior improvements strength, power, sprint and change of direction compared to FAIL and significantly superior efficiency for improving SQppr and SQ1RM.

As expected, FAIL group recorded a superior volume load compared to NO-FAIL. FAIL group was projected to amass ~ twice as much volume as NO-FAIL, instead the difference ended up being lower. Similarly to what reported by Painter and colleagues (Painter et al., 2012), the accumulative fatigue in successive weeks comported a reduction of the repetitions completed by FAIL training group during the latter part of the study, driving down volume load.

Body mass, QuadCSA and HamCSA did not vary across time. The duration of the training intervention (seven weeks) was not sufficient to produce the desired alteration in muscle size in trained individuals (Prestes et al., 2019; Schoenfeld, 2010; Schoenfeld, Grgic, et al., 2017). Still, ES, while being null for body mass, contrary to what was possible to expect due to the inferior training volume (Schoenfeld, Ogborn, & Krieger, 2017a, 2017b), NO-FAIL was advantageous for muscle dimension adaptations. This can be explained by the exercises selection (SQ, DL), with numerous players squatting with a more powerlifting-like style technique (Pham, Machek, & Lorenz, 2020), with the bar positioned low on the shoulders, resulting in a motion imposing greater torque on the hip-joint than knee-joint (Glassbrook, Brown, Helms, Duncan, & Storey, 2019). These exercises elicit a greater posterior-chain muscle involvement, and greater proximal rather than distal muscle activation (Glassbrook, Helms, Brown, & Storey, 2017; Martín-Fuentes, Oliva-Lozano, & Muyor, 2020). Therefore, It is possible that hypertrophy occurred non-homogeneously (Zabaleta-Korta, Fernández-Peña, & Santos-Concejero, 2020), and increases in CSA localized at a more proximal point on the thigh could not be detected by mid-thigh measurements of circumferences and skinfolds.

The lack of effects of the training program on vertical jump performance can be due to the training lack of specificity. Really, no jumping activities had been completed by players in both groups. This is in accordance with further literature, (K. M. Carroll, Bernards, et al., 2019; Izquierdo et al., 2006) in which no between groups differences were present at the end of the maximal strength training block. Differences arose, in both cases, only after the power training block during which the subjects performed rocket jumps or unloaded and loaded CMJs, respectively. Between groups comparison showed opposing results, with CMJ favored by NO-FAIL and CMJA by FAIL. In CMJA, thanks to the intervention of the upper limbs during the lowering of the players' centers of mass, higher eccentric forces are registered (Everett A. Harman, Rosenstein, Frykman, & Rosentstein, 1990). During the intervention, the only exercise prescribed for the lower body that involved an eccentric phase is the SQ and, while NO-FAIL completed 182 repetitions, FAIL totaled nearly double than that. Furthermore, FAIL completed abundance of strenuous repetitions. It is therefore possible that FAIL provided superior eccentric training stimulus (Illera-Domínguez et al., 2018), enabling players to withstand the superior eccentric force during the unwinding phase of the CMJA and producing a larger net impulse (Sole, Mizuguchi, Sato, Moir, & Stone, 2018).

As expected, an increase in the F0r in the SQ f-v profile occurred over time. A number of studies reported improvements in movement velocity against heavy loads after a program targeted at maximal strength (Jiménez-reyes, Samozino, Brughelli, & Morin, 2017; Morin & Samozino, 2016; Samozino & Morin, 2015). No variations in V0 or slope were reported, while an increase in SQppr, driven by superior force production capabilities, is present. While NO-FAIL carried a small advantage over FAIL in SQV0 and SQF0r, a large effect for SQppr is present. The lower accumulative fatigue throughout the training program is a result of a lower volume of work (Bishop, Jones, & Woods, 2008; Häkkinen, 1993) and the lack of sets leading to muscular failure (Morán-Navarro et al., 2017). could have allowed NO-FAIL to consistently train with a readier neuromuscular system. This would have provided for higher movement displacement velocities against the same loads, due to greater magnitudes of force applied into the ground, leading to superior strength and power adaptations (Behm & Sale, 1993).

The improvements in SQ1RM and DL1RM in both groups are consistent with the rate of improvement in similar training studies across a maximal strength training phase (~ +10%) (Argus et al., 2010; Izquierdo et al., 2006; Painter et al., 2012). In accordance with the literature, the initial changes in strength are most likely the effect of neural and motor adaptation rather than structural modification (T. J. Carroll, Riek, & Carson, 2001; Prestes et al., 2019). Medium ES in favor of NO-FAIL were present. Again, this superior adaptation, confirms measurements from the f-v profile and can be due to training with a more rested neuromuscular system, allowing for better control over execution of technique (Aune, Ingvaldsen, & Ettema, 2008; Taylor, 2015). For example, during the SQ, as the quadriceps fatigue, the biomechanics of the movement changes to a more hip dominant exercise (Trafimow, Schipplein, Novak, & Andersson, 1993). The technique changes that occur during the last repetitions do not favor technique acquisition and optimal strength development (Hooper et al., 2014).

Despite the presence of the weekly sprint training session, no significant effects on speed performance were present. On the other hand, ES analysis clearly favors NO-FAIL. To the author's knowledge, this is the only study in the literature dealing with the transfer effect of the RT protocols onto linear or change of direction speed. Lower levels of fatigue prior to the sprint training session allowed the players in NO-FAIL group to consistently sprint faster and therefore achieve a greater stimulus, at the same volume, from the superior intensity (speed) of the task. This speculation can be supported also by the smaller ES in favor of NO-FAIL for CoD505. No CoD sprint was prescribed during the training intervention, as players relied solely on on-field practice activities to continue practicing this skill (Kempton, Sirotic, & Coutts, 2015). Sprint improvement in NO-FAIL, exceeding those assessed for the other skills, must come from a superior stimulus in the sprint session itself. Another possible explanation, regarding the small between groups ES for CoD505, is that, although both RT programs lead to a statistically significant improvement, FAIL provided a superior stimulus for the substantial eccentric force production required for the sudden deceleration present in the test, as eccentric training has been shown to consistently improve CoD in football players (Chaabene, Prieske, Negra, & Granacher, 2018; de Hoyo et al., 2016; Núñez et al., 2018).

The results suggest a superior training efficiency of NO-FAIL in improving strength and power in the back squat, given the substantial differences in volume loads between groups and the statistically significant differences from the Mann-Whitney test. On the other hand, force absorption capabilities, in accordance to the literature, seem to benefit from a larger exposure to eccentric training (Suchomel, Wagle, Douglas, Taber, Harden, Gregory Haff, et al., 2019; Suchomel, Wagle, Douglas, Taber, Harden, Haff, et al., 2019).

Overall, training to failure is not supported by the results in this study, in accordance with a recent review that highlights the key role of fatigue management during RT. More articulated load prescription modalities, capable of greater regulation of the relative intensity of the stimulus can lead to superior training results (Thompson et al., 2020). An example is the use of the relative intensity based on sets and repetitions (Duca & Alberti, 2020; Suarez et al., 2019), which allows to selection of different relative intensities throughout the training week and from week to week, allowing for training at a broader range of overloads and better managing accumulative fatigue.

This study is not without limitations, the first is the lack of any direct measurement of force, both concentric and eccentric force production capabilities could only be indirectly inferred from other measurements. Additionally, the lack of a longer tapering, including test specific activities (i.e. vertical jumps), can have blunted the possibility to detect further difference between groups.

3.5. CONCLUSION

In the present study, the effects of resistance training to failure on measures of lower body size, strength, power, and sprint and change of direction were assessed in rugby union players. After a seven-week long training intervention training to failure elicited overall poorer adaptations when compared to training not to failure, especially when considering the between groups differences in training volumes. Thanks to lower levels of accumulated fatigue, training not to failure elicited superior adaptations in maximal strength and power, that could result in a superior transfer effect on linear and change of direction speed. Still, the paucity of eccentric loading could have provided a sub optimal stimulus towards improving the players' force absorption capabilities.

Therefore, due to the reduced volume load and greater between groups' effects on physical performance outcomes, resistance training not to failure is a suggested prescription method for improving strength, power and speed in rugby union players. The coaches should choose a resistance training prescription method that allows the players to exercise at submaximal training intensities and vary the relative intensity throughout the week and from week to week, managing accumulative fatigue and allowing for superior strength and power adaptations.

4. GENERAL CONCLUSIONS

Rugby union is a sport characterized by high-intensity actions for which players must display a wide arrange of physical abilities as they are required to sprint, jump, tackle, and fight for the control of the ball. Size, strength and power capabilities are key towards success and discriminate between lower and higher-level players. This thesis provides additional evidence in discerning between national and international level Italian junior rugby players, as maximal strength in the squat exercise has been proven as selection predictors. To increase size, strength and power a multitude of resistance training approaches can be adopted, with the majority of research in rugby employing prescription methods that requiring consistent use of training to local muscular failure. Yet, evidence from other contexts informs that muscular failure is not necessary for increasing body size and even detrimental for improving strength and power. This thesis tested this hypothesis in rugby union players. Thanks to inferior levels of accumulated fatigue throughout the intervention, training not to failure elicited superior adaptations in maximal strength, power, and sprint performance.

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Index of abbreviations:

1RM = one repetition max

BKS = back players

BMI = body mass index

BP = bench press

BP1RM = bench press one repetition max

BR = bench row

BR1RM = bench row one repetition max

NO-FAIL = training not to failure

CMJ = countermovement jump

CMJA = countermovement jump with arm swing

CoD505 = 5-0-5 change of direction test time

DL = deadlift

ES = effect size

F0r = maximal theoretical relative force of the force-velocity profile

FAIL = training to failure group

ft = flight time

FWS = forward players

h = height

HamCSA = hamstrings cross sectional area

mm = momentum

pp = peak power

ppr = peak power relative to body-mass

QuadCSA = quadricep cross sectional area

RT = resistance training

slope = slope of the force-velocity profile in the back squat

SQ = back squat

V0 = maximal theoretical velocity of the force-velocity profile

t = time

APPENDIX

Script used in the software R to compute the logistic regression and plot Figure 2.9.

```
data<-read.csv(file.choose(), header=T)

head(data)

model<-glm(selection~Bodymass + CMJpp + 10mm + 30mm + SQ1RM + DL1RM + BP1RM,
data=data, family=binomial)

library(car)

durbinWatsonTest(model) #checking for independence of error

ln. Bodymass <-log(data$ Bodymass)

ln. CMJpp <-log(data$ CMJpp)

ln. 10mm <-log(data$ 10mm)

ln. 30mm <-log(data$ 30mmm)

ln. SQ1RM <-log(data$ SQ1RM)

ln. DL1RM <-log(data$ DL1RM)

ln. BP1RM <-log(data$ BP1RM)

ln.m<-glm(selection~ Bodymass + CMJpp + 10mm + 30mm + SQ1RM + DL1RM + BP1RM +
Bodymass*ln.Bodymass + CMJpp*ln.CMJpp + 10mm*ln.10mm + 30mm*ln.30mm +
SQ1RM*ln.SQ1RM + DL1RM*ln.DL1RM + BP1RM*ln.BP1RM, data=data, family=binomial)

LM<-log(fitted(model)/(1-fitted(model))) #Looking for no statistical interaction
between an IV and its natural log form.

plot(LM, data$ SQ1RM) #Looking for obvious linear relationship in the plot

summary(ln.m)

summary(model)$dispersion #checking for overdispersion. >1 indicates
overdispersion.
```

```
library(perturb) #Checking for multicolinearity.

cd<-colldiag(model)

print(cd, dec.places=2) #If two or more variables (not constant) have variance proportion > 0.5 AND they also have condition index > 30, your model is likely plagued with multicollinearity.

#Checking for influential case - all meterics are saved with the original data exported into R. The more of the listed criteria are met, the more likely the subject is an influential case.

data$cooks<-cooks.distance(model) #cooks distance - >1

data$zres<-rstandard(model) #stadrdized residuals - >2 or <-2.

data$leverage<-hatvalues(model) #leverage values a.k.a. hat values. >2((k+1)/N): k = number of independent variables and N - total sample size

data$covariance.ratio<-covratio(model) #covariance ratio. Possible influential case if a covariance ratio is outside the range of 3((k+1)/N)-1 to 3((k+1)/N)+1.

data$check.cooks<-ifelse(data$cooks>1, "IC", "")

data$check.zres<-ifelse(abs(data$zres)>2, "IC", "")

data$check.lev<-ifelse(data$leverage>2*((3+1)/nrow(data)), "IC", "")

data$check.cov<-ifelse(data$covariance.ratio<3*((3+1)/nrow(data))-1, "IC", ifelse(data$covariance.ratio>3*((3+1)/nrow(data))+1, "IC", ""))

data

summary(model)

library(popbio)
selection<-data$selection
SQ1RM<-data$SQ1RM
logi.hist.plot(SQ1RM,selection,boxp=FALSE,type="hist",col="gray")
```