The utilisation of the Rugby League Athlete Profiling battery for assessing the anthropometric and physical characteristics of rugby league players

This thesis is submitted in accordance with the requirements of the University of Chester for the degree of Doctor of Philosophy

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Declaration of Originality

This work is original and has not been previously submitted in support of a degree qualification or other course.

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Abstract

The research described in this thesis used a standardised battery of tests called the 'Rugby League Athlete Profiling (RLAP)' battery for assessing the anthropometric and physical characteristics of UK-based rugby league players. The overall purpose of this research was to determine the utility of the RLAP battery, which involved establishing the use of RLAP across numerous professional clubs over a three-year period, determining the measurement properties of the tests included and investigating the factors associated with a change in the characteristics.

An early version of the RLAP battery existed [called SPARQ] and was provided by the Rugby Football League with scope to alter this as part of this programme of research. Before determining if an alteration to the battery was required, it was essential to understand the tests that are currently used in rugby league for assessing the anthropometric and physical characteristics of players. As such, the systematic review initially sought to determine the volume of performance tests used in rugby league along with their measurement properties. Based on the results, it was evident that a shorter sprint distance (< 20 m) ought to be included in the battery. It was also clear that only one field-based method for measuring muscle strength was available, though had received minimal research. Furthermore, the review highlighted that no rugby-specific intermittent running test had previously been used and that RLAP was the first battery to include such a test. Therefore, based on these results, the battery was rebranded to RLAP, which included a stature, body mass, a 10 m and 20 m sprint test, a rugby-specific intermittent test, a change of direction test, measures of lower- and whole-body power.

With the RLAP battery confirmed, it was then used and the reliability (Chapter 4) and discriminant validity (Chapter 5) of its elements determined. Results indicated that the RLAP battery is reliable and does not require habituation. Furthermore, the calculation of the required change, which includes the worthwhile change and random error of each test, provides researchers and practitioners with a single value that can be used as an analytical goal to evaluate a true change in characteristics with confidence. All components of the RLAP battery (except 10 m sprint time) possessed adequate discriminant validity between youth, academy and senior rugby league players, suggesting this battery can accurately distinguish between playing standards.

As noted in above, the review highlighted a rugby-specific intermittent test has yet to be established in the literature before its inclusion in the RLAP battery. Whilst it appeared to be suitable and, based on Chapters 3 and 4, is reliable and possesses discriminant validity, the test itself had received no previous attention. Given the novelty of this test, it was unknown if this test was better associated with the responses to rugby league match performance and what the physiological responses were to this test. As such, Chapter 5 sought to determine the concurrent validity of this test and compare it against the traditional Yo-Yo Intermittent Recovery test level 1 (Yo-Yo IR1). The results indicated the association between prone Yo-Yo IR1 distance and the external, internal and perceptual responses to simulated match-play was improved when compared to the Yo-Yo IR1. Chapter 6 demonstrated that starting each 40 m shuttle in a prone position increases the internal, external and perceptual loads whilst reducing the total distance achieved. The degree of shared covariance between the prone Yo-Yo IR1 and Yo-Yo IR1 suggest the rugby-specific test provided insight into additional characteristics associated with rugby league performance.

In studies that have reported on the anthropometric and physical characteristics, few have considered the multiple factors that might influence these with no studies conducted in rugby league. Chapter 7 sought to determine the complex interaction between anthropometric and physical characteristics that requires careful consideration by those involved in developing youth and academy athletes. The results also revealed a number of contextual factors such as season phase, league ranking, playing age and playing position that can influenced the change in characteristics over the course of a competitive season. The findings of this study highlight how some characteristics are impaired towards the end of the season, thus providing a rationale for considering in-season training loads and the application of short training interventions to off-set these negative changes.

Based on negative changes in some anthropometric and physical characteristics towards the end of the year, Chapter 8 reported on the efficacy of two in-season sprint interval interventions for enhancing the physical characteristics of rugby league players. Furthermore, the study provided insight into the sensitivity of the RLAP battery for detecting changes in the characteristics of rugby league players. The results highlighted that two weeks of rugby-specific and running-based sprint interval training appeared affective for promoting the physical characteristics of rugby league players with minimal deleterious effects on wellness and neuromuscular function. Using the reliability statistics from Chapter 1, the mean change for prone Yo-Yo IR1 in the rugby-specific group met the required change whilst changes approached this value for the running-based group despite contrasting loads. In all, this study demonstrated that sprint interval training that includes sport-specific actions is a suitable and effective training modality that can be used in-season. In addition, the result demonstrated how the prone Yo-Yo IR1 was sensitive to change across the intervention period whilst others were not sensitive to sprint interval training due to the lack of specificity.

This thesis provides a thorough evaluation of the RLAP battery that can be used by researcher and practitioners to assess the anthropometric and physical characteristics of rugby league players. The battery is reliable and possess discriminant validity, while the prone Yo-Yo IR1 has concurrent validity and is sensitive to change during a low-volume in-season training intervention. Overall, this thesis provides justification for the tests included and comprehensively examines the utility of this battery for assessing the anthropometric and physical characteristics of rugby league players. Practically, this battery of tests can be used by researcher and applied practitioners in rugby league with an understanding of the reliability, validity and sensitivity of the tests along with some factors that might influence the characteristics of players across a season.

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List of abbreviations

$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}CO_{2peak}$	Peak carbon dioxide production.
$\dot{V}_E$	Minute ventilation
$\dot{V}E_{peak}$	Peak ventilation
$\dot{V}O_2$	Oxygen uptake
$\dot{V}$O2max	Maximal oxygen uptake
$\dot{V}O_{2peak}$	Peak oxygen uptake
$[La]_b$	Blood lactate concentration
%BF	Percentage body fat
$\%HR_{peak}$	Percentage of peak hear rate
2C, 3C	2 or 3 compartments
$30\text{-}15_{IFT}$	30-15 intermittent fitness test
3G	3^{rd} generation artificial turf
90% CI	90% confidence intervals
95% CI	95% confidence intervals
AAA	Athletic ability assessment
ADP	Adenosine diphosphate
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
AU	Arbitrary unit
BMC	Bone mineral content
BMI	Body mass index
Ca2+	Calcium ions
CMJ	Countermovement jump
CV%	Coefficient of variation
dRPE	Differential rating of perceived exertion
dRPE-B	Differential rating of perceived exertion for breathlessness
dRPE-L	Differential rating of perceived exertion for legs
DXA	Dual Energy X-ray Absorptiometry
ES	Effect size
FFM	Fat free mass
FM	Fat mass
FMS™	Functional movement screen

GPS	Global positioning system
HDOP	horizontal dilution of precision
HIIR	High intensity intermittent running
HMP	High metabolic power
HR	Heart rate
HR_{mean}	Mean heart rate
HR_{peak}	Peak heart rate
HRR	Heart rate recovery
ICC	Intraclass correlation coefficient
ISAK	International Society for Advancement Kinanthropometry
LM	Lean mass
LMI	Lean mass index
MAS	Maximal aerobic speed
MBI	Magnitude based inferences
MSFT	Multi-stage fitness test
PRISMA	Preferred reporting items for systematic reviews and meta analyses
Q	Quartile
Q-Q plot	Quantile-to-quantile plot
QMA	Qualitative movement assessment
RHIE	Repeated high intensity effort
RLAP	Rugby League Athlete Profiling
RLMSP-i	Rugby League Match Simulation Protocol for interchange players
RM	Repetition maximum
RPE	Rating of perceived exertion
RSA	Repeated sprint ability
RSI	Reactive strength index
SD	Standard deviation
SIT	Sprint interval training
SIT_r	Running-based sprint interval training
$SIT_{r/s}$	Rugby-specific sprint interval training
SPARQ	Speed, Agility, Reaction, Quickness
sRPE	Session rating of perceived exertion
SUM[number]	The sum of multiple skinfold sites
SWC	Smallest worthwhile change
TE	Typical error

TID	Talent identification and development
V_{IFT}	Maximal running speed
VJ	Vertical jump
Yo-Yo IR1	Yo-Yo Intermittent Recovery Test Level 1
Yo-Yo IR2	Yo-Yo Intermittent Recovery Test Level 2
YPHV	Years at peak height velocity

Publications based on the thesis studies

Dobbin, N., Hunwicks, R., Highton, J., & Twist C. (2017). A reliable testing battery for assessing physical qualities of elite academy rugby league players. *Journal of Strength and Conditioning Research, 31*(11), 3232-3238.

Dobbin, N., Highton, J., Moss, S. L., & Twist, C. (2019). The discriminant validity of a standardised testing battery and its ability to differentiate anthropometric and physical characteristics between youth, academy and senior professional rugby league players. *International Journal of Sports Physiology and Performance,* doi: 10.1123/ijspp.2018-0519.

Dobbin, N., Moss, S. L., Highton J., & Twist, C. (2018). An examination of a modified Yo-Yo test to measure intermittent running performance in rugby players. *European Journal of Sport Sciences, 18*(8), 1068-1076.

Dobbin, N., Highton, J., Moss, S. L., Hunwicks, R., & Twist, C. (2018). Concurrent validity of a rugby-specific yo-yo intermittent recovery test (level 1) for assessing match-related running performance. *Journal of Strength and Conditioning Research,* doi: 10.1519/JSC.0000000000002621.

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Dobbin, N., Highton, J., Moss, S. L., & Twist, C. (*in-press*). The effects of in-season, low-volume sprint interval training with and without sport-specific actions on the physical characteristics of elite rugby league players. *International Journal of Sports Physiology and Performance.*

Additional supporting publications

Dobbin, N., Gardner, A., Daniels, M., & Twist, C. (2018). The influence of preseason training phase and training load on body composition and its relationship with physical qualities in professional junior rugby league players. *Journal of Sport Science, 36*(4), 2778-2786.

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Dobbin, N., Highton, J., Moss, S. L., Hunwicks, R., & Twist, C. (2017). The validity of a rugby-specific yo-yo intermittent recovery test for assessing match-related running performance. *Conference of the World Rugby Science Network 2017 12th September, University of Bath.*

Dobbin, N., & Till, K. (2017). Physical profiles and development of adolescent rugby league players. *Rugby Football League Medical, Science and Coaching Forum 2017, 10th & 17th May, Leeds Beckett University & University of Chester.*

Dobbin, N. (2017). Anthropometric and physical qualities: creating national performance standards. *Rugby Football League Category 3 Coaching Forum, 2018, 14th February, Red Hall, Leeds.*

Chapter 1

Introduction

1. Introduction

1.1. An introduction to rugby league

Rugby league originated in 1895 after twenty-two clubs from Yorkshire, Lancashire and Cheshire resigned their membership of the now Rugby Football Union to establish their own league, the Northern Rugby Football Union.[80] The split from the Rugby Union subsequently resulted in a professionalisation of the game, significant rule changes, and greater emphasis placed on league and cup fixtures. Approximately a century later, on the 30th April 1995, the Premier League was renamed 'The Super League', which continues to have significant financial implications for both the sport's governing body and individual clubs through increased sponsorships, merchandise and media rights.[206] The re-structuring of the leagues in the 1990s also brought about promotion and relegation across the three tiers. As such, the importance of winning games, leagues and cup competitions became a major focus for all teams within the league given the prestige, recognition and financial implications this might have. Indeed, with an increased importance of winning, clubs have sought to establish strategies that maximise their chance of success including the integration of sport science disciplines. One area that has received considerable attention with this regard is talent identification, which refer to the process of recognising individuals with potential, and talent development, referring to the opportunity provided to players in order to realise this potential.[259]

The game of rugby league is typically classified as a high-intensity, intermittent, collision-based sport and is played worldwide, with professional teams largely based in the UK and Australasia.[29,98,107] The game involves 13 on-field players and 8 interchanges who have specific roles depending on their playing position, which are typically split into positional groupings (i.e. hit-up forwards, adjustables and outside backs). Rugby league match-play comprises two 40-minute periods interspersed with a 10-minute half-time period and is contested on a 120 m x 58-68 m grass or artificial surface. The game is played at junior, youth and senior age-groups at amateur, semi-professional and professional standards. Junior rugby league includes players at U7 years through to U15, whilst youth rugby league includes U16 through to U18. From here, players aged 16 and above are permitted to play open-age male rugby league.

The game of rugby league has evolved substantially over recent years, with several significant rule changes that have potentially impacted on the demands of the game as well as the anthropometric and physical characteristics of players.[107] For example, for the 2012 season the number of interchanges was reduced from 12 to 10 in an attempt increase the playing time of forwards. This rule has recently been changed further for the 2019 season with the number of interchanges now at 8. Another rule change that potentially influenced the anthropometric and physical characteristics included the 20 m restart and "zero tackle", whereby the defensive team now defend an additional tackle. Changes have also occurred with regards to salary caps and exemptions throughout the game. For example, the sport's governing body, The Rugby Football League (RFL), introduced a policy whereby players who are able to play at U21 are exempt from the club's salary cap. As such, this encourages teams to promote from within and gives young "talented" players the opportunity to develop and progress to professional senior rugby league. This, in part, has placed greater emphasis on talent identification and development programmes in rugby league with the majority of clubs now employing coaches to support the transition between youth and academy, and academy and senior rugby league.

1.2. Physical characteristics of rugby league players

Rugby league training and match-play places high physical loads on players across all age categories, playing positions and playing standards, the demands of which have been well-documented.[26,57,58,72,102,138,155,258,263,266] To tolerate these demands, it is necessary for players to possess well-developed anthropometric and physical characteristics such as appropriate body composition, lower- and upper-body power, speed, change of direction ability and aerobic- or intermittent running capacity.[43,94,98] In addition, the increased focus on talent identification and development through financial incentives and specialised coaching roles within professional clubs, highlights the importance of understanding and developing the anthropometric and physical characteristics of players.[193,241,255,259,270] Over the last decade, several researchers have sought to investigate the anthropometric and physical characteristics of junior, academy and senior rugby league players at amateur, semi-professional and professional standards.[98,107,255] Indeed, the current literature demonstrates how such characteristics can impact match[124] and technical performance (i.e. tackling),[114,231,232] team selection,[104,115,257] and long-term progression,[241,242,246,254] and can discriminate between playing standards,[106,110,115,160] positions,[94,105,189] age groups[46,109,242,256] and maturation status.[240,244] Whilst it is important to acknowledge the complex interactions between technical, tactical, cognitive and social factors that influence a player's ability and progression, it is evident that anthropometric and physical characteristics play an important role in the science of rugby league.[98,255]

Studies investigating the anthropometric and physical characteristics of rugby league players have focused on strength, power, speed, change of direction and aerobic- or intermittent running capacity using a range of performance tests.[43] The physical characteristics assessed across studies, as well as variances in testing procedures have resulted in a large volume of research that cannot be compared across playing groups,[255] thus limiting its usefulness in the applied environment. For example, the ability to compare a club's players with 'normative data' in order to support the development of athletes is difficult. Consequently, it was recently recommended that a National Standardised Battery of tests be developed and implemented in rugby league to provide 'true' normative data.[255] In addition, a limited number of studies have included data collected from multiple clubs, resulting in characteristics that are likely to be affected by a range of factors, such as expertise, training practices and talent identification and development programmes. Finally, it is also the case that the majority of research has focused on youth athletes,[255] with limited studies providing normative data on athletes over the age of 16 years (i.e. academy) and senior professional players. Such information seems important to understand if, and to what extent, differences exist between playing groups. This information could then be used to provide athletes with the necessary training and support to minimise the performance discrepancy with those athletes completing at a higher playing standard.

1.3. The Rugby League Athlete Profiling battery

To address some of the issues around the variance in tests employed across Super League-affiliated clubs, achieve strategic objectives such as establishing position-specific performance standards, and integrate research and innovation league-wide, the RFL purchased a battery of performance tests that were packaged and sold as Nike's SPARQ (speed, power, agility, reaction and quickness) battery. The tests included have been used across numerous other sports including American football, soccer, baseball and basketball with each battery modified in some way depending on the needs of the sport. Nike's SPARQ battery was chosen by the RFL as this was portable, field-based, inexpensive, suitable for all ages, efficient and able to be conducted by an independent researcher initially and then carried out by club practitioners. The battery of tests included a 20 m sprint test a medicine ball throw, agility shuttle test, modified Yo-Yo IR1 and a vertical jump, though there was scope to adapt or add/remove tests from the battery at the start of the programme of research if necessary. It was therefore important to establish if the battery provided by the sport's governing body was suitable. Some questions were initially raised by the author of this thesis as to whether that battery assessed the characteristics its acronym claimed (SPARQ). For example, no measure of reaction time was included in any test, the distinction between speed and quickness was not clear, and the test of agility was pre-planned and therefore change of direction was a more appropriate description. Due to this, and the small changes made, the battery of tests was renamed the Rugby League Athlete Profiling (RLAP) battery to identify it as rugby-specific and unique to the RFL.

As part of the programme of research, there were a number of initial research questions from the RFL around the reliability and validity of the RLAP battery as well as the need to establish normative data and integrate the battery as part of practice. Furthermore, as the PhD progressed, several additional research questions emerged around some tests included in the RLAP battery, what factors influence the anthropometric and physical characteristics, and if they are sensitive to changes in performance.

1.4. Aims and objectives of the research programme

The overall aim of this research was to examine the utility of a the RLAP battery for assessing the anthropometric and physical characteristics of UK-based rugby league players as well as integrating this into applied practice and establishing a league-wide normative data set for the governing body. To determine the utility of the RLAP battery, a number of specific aims were developed focusing on reliability, validity, factors affecting the anthropometric and physical characteristics of rugby league players and sensitivity of RLAP.

To aid with the interpretation of data from a battery of tests for the anthropometric and physical characteristics, it is essential researchers and practitioners have an understanding of the within-subject (random) variation of the dependent variable(s) from the RLAP battery. The reliability of tests that assess the anthropometric and physical characteristics can generally be categorised as changes in the mean, typical error and retest correlation. I addition, recent research has sought to determine the meaningful change (i.e. smallest worthwhile change) in the score across a range of performance tests that can support the interpretation of data.[133,234] Finally, it is important when determining the reliability of any performance test, the extent to which habituation is required using an appropriate sample size. Therefore, the aim of Study 1 was to determine the reliability of the RLAP battery including the aforementioned statistics, three assessments to check if habituation is necessary, and use of a sample size that is sufficient for an accurate measure of the error.

A second aim for this research was to determine the extent to which the tests included in the RLAP battery could discriminate between playing standard as well as achieving one of the RFL's objectives, which was to establish position-specific normative data across, youth, academy and senior standards. The extent to which the RLAP tests and battery as whole discriminate between playing standards is valuable for coaches and practitioners concerned with athlete development in order to set appropriate targets or focus training in an attempt to minimise the performance discrepancy between youth and academy, and academy and senior players. To this end, Study 2 involved assessing youth, academy and senior players using the RLAP battery across a three-year period to determine the discriminant validity and establish age- and position-specific normative data.

The battery of tests originally purchased by the RFL included a modified Yo-Yo Intermittent Fitness Test (Yo-Yo IR1) that formed a key part of the RLAP battery. Initially, its inclusion was based on an assumption this better reflected the demands of rugby league. However, with the systematic review of the literature highlighting that this test had not previously been used in rugby league, its association to rugby league performance was unknown as was the physiological responses to the tests. Therefore, it was necessary to understand this test in greater detail. Therefore, the aim of Study 3 was to determine if, and to what extent, the modified Yo-Yo IR1 was associated (concurrent validity) with the physiological responses to rugby league performance and whether this association was improved compared to the standard Yo-Yo IR1. Study 4 sought to understand the internal, external and perceptual responses the modified Yo-Yo IR1 test and determine if these were different to the standard Yo-Yo test thus, providing some insight into the physiological construct being assessed.

With an understanding of measurement properties of the RLAP battery (Chapter 3, 4 and 5), it is important to understand the factors associated with the change in physical characteristics across a rugby league season. Further, the development of a youth, academy and senior players characteristics is a key focus for rugby league coaches and practitioners in the short- (i.e. preseason; Appendix 13),[200] medium- (i.e. season)[253] and long-term (i.e. multiple seasons).[262] However, little is currently known about the contextual factors that influence these characteristics in rugby league. In soccer, Mohr and Krustrup[196] demonstrated that playing position, season phase and final league position were associated with Yo-Yo IR1 performance, but no such studies currently exist in rugby league. The aim of Study 5 was therefore to investigate the extent to which contextual factors such as season phase, playing age and league position were associated with changes in physical characteristics using the RLAP battery across a competitive rugby league season.

One of the contextual factors included in Study 5 that is of particular interest was season phase with results highlighting impairment of some characteristics between the middle and end of season assessments. Such findings might have important implications for the progression of players and team performance during a key stage of the season. The inclusion of short, high-intensity training modalities that provide potential stimulus for improving players' physical qualities without eliciting deleterious effects on wellbeing and neuromuscular function might be an effective strategy for rugby league practitioners and players. It also raises important questions regarding the sensitivity of the RLAP battery to detect a change in performance. Recent work has reported the benefits of low-volume sprint interval training,[38,183,239] though this is currently limited to soccer and fails to consider the fatigue responses or the inclusion of sport-specific actions. As such, Study 7 sought to determine the effects of two in-season, low-volume sprint interval interventions on the physical characteristics of rugby league players as determined by the RLAP battery.

1.4. Organisation of empirical studies

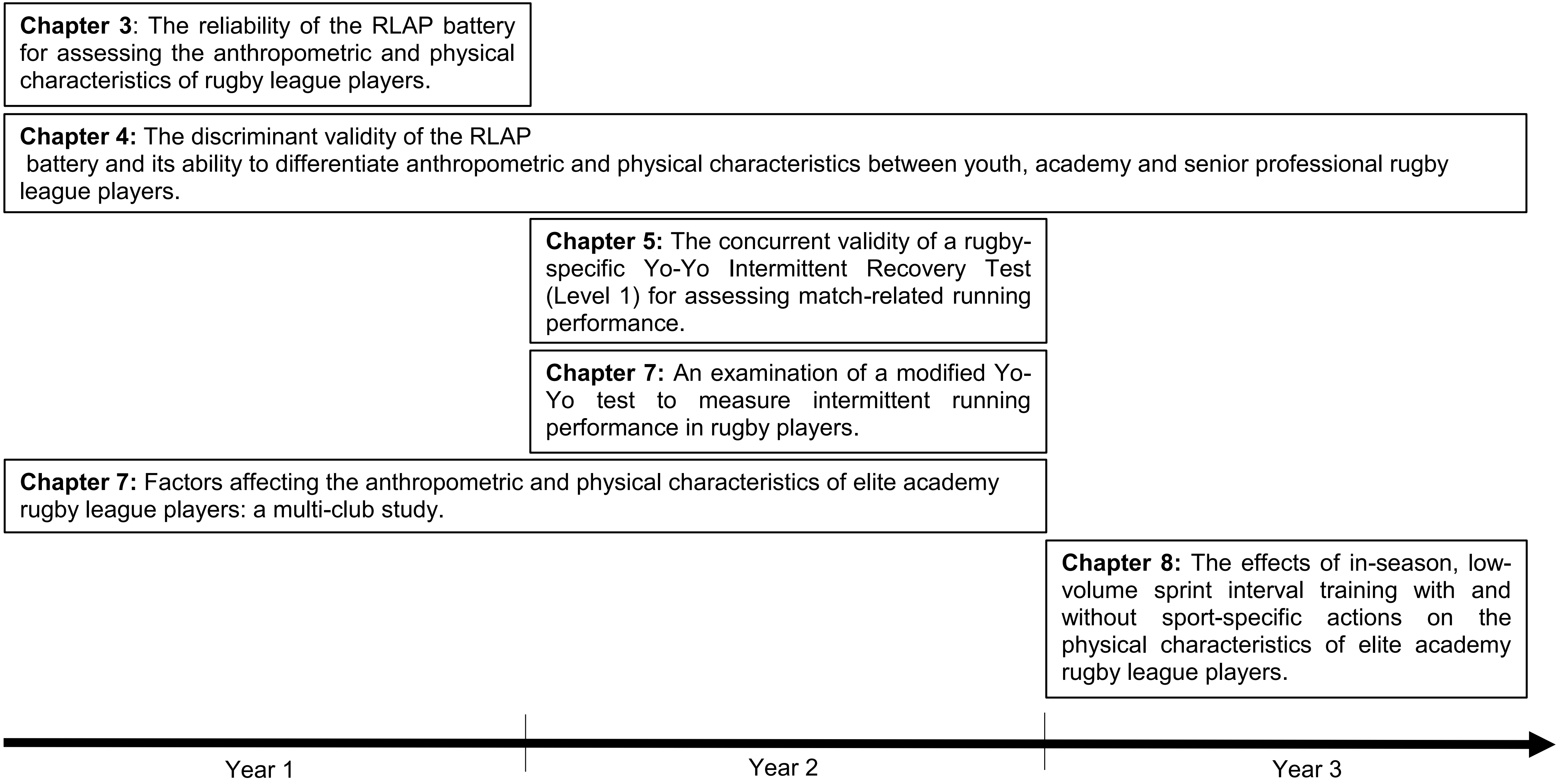

Figure 1. Chronological organisation of empirical studies

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Chapter 2

A systematic review of performance tests for assessing the anthropometric and physical characteristics of rugby league players.

This chapter systematically reviewed the current performance tests used in rugby league for assessing anthropometric and physical characteristics. The review served to determine if the RLAP was suitable or if any alterations to the battery provided by the Rugby Football League was required before implementation. Findings supported the use of stature, body mass, muscle power and change of direction ability. Moreover, the review highlighted that no rugby-specific test for prolonged high-intensity intermittent running was available and that a shorter sprint distance should be included in the battery.

2.1. Introduction

Rugby league is played at junior and senior levels worldwide, with professional teams largely based in the UK, France, Australia and New Zealand.[29,107] A rugby league team consists of 13 on-field players, four replacement players and a maximum of eight interchanges, with the game characterised as a high-intensity collision sport played over two 40-minutes halves.[107] During match-play, players engage in frequent bouts of high-intensity efforts interspersed with low-intensity activity.[93,258] Previous research has reported that players cover total distances of between 4000 and 7000 m (89 to 95 $m \cdot min^{-1}$), sprinting distances of between 119 and 316 m (0.36 to 0.44 $m \cdot min^{-1}$)[72,263] and between 15 to 30 collisions (0.2 to 0.8 $n \cdot min^{-1}$).[58]

To cope with the demands of match-play and training, rugby league players are required to possess appropriate anthropometric and physical characteristics, combined with range of game-specific skills. To date, much of the research has focused on the anthropometric and physical characteristics of junior players, which has been reviewed in detail previously.[167,255] The assessment of anthropometric and physical characteristics of rugby league players serves a number of important functions. For the club, the use of these data allows them to create ‘performance standards’, aid talent identification,[243,257] inform team selection,[104,106] and support the progression of players through to senior rugby.[242,254] NGBs such as the RFL also have a vested interest in assessing the characteristics of players as it enables them to highlight areas for future development (i.e. talent development), explore longitudinal recruiting across the league,[210] inform selection for the national side,[243] focus financial resources and contributed to funding bids from organisations such as Sport England.[75,247]

A large base of scientific literature now exists documenting the anthropometric and physical characteristics of rugby league players, which has been driven by the need to understand which performance tests can discriminate between players of different standards[13,160] and positions[105] if, and to what extent, they influence on-field performance,[92,168] and which tests can be used to monitor changes in performance.[200] A review of the literature reveals the wide array of performance tests currently available[43] and has led to others suggesting there is a need for a standardised battery of tests that can be used across several playing standards.[255] In addressing this need, the RFL sought to establish a standardised battery that can be employed across the UK. However, before a standardised battery of tests can be employed, such as Nike's SPARQ battery proposed by the RFL, there is a need to identify the tests currently being used along understanding the physiological construct being evaluated to ensure that the most appropriate tests are included in the battery, whilst also ensuring it is feasible within the applied environment (i.e. portable, efficient and low cost). Furthermore, a thorough evaluation of the measurement properties (i.e. reliability, validity and sensitivity) is warranted to aid practitioners and researchers in selecting or justifying tests to be included in the battery, particularly when used to support talent identification and development, detecting training-induced changes, discriminate between players and/or influence on-field performance.

The aim of this systematic review was to examine the tests currently used in rugby league to determine the anthropometric and/or physical characteristics of rugby league players and report on their measurement properties with a view of optimising the proposed battery of tests provided by the RFL.

2.2. Methods

2.2.1. Study design

A systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) statement.[195] Stage 1 of the review included all articles that assessed the anthropometric and/or physical characteristics of male rugby league players. Stage 2 involved the determination of articles that addressed the concurrent validity, discriminant validity, reliability and/or sensitivity.

2.2.2. Search strategy

An electronic database search was conducted of PubMed, SportDiscus, ScienceDirect, Medline and Web of Science with searches limited to articles published after the start of Super League (1996) and was completed in June 2018. A Boolean search phrase was created with the support of a subject librarian and included the following search strategy: ‘change’, ‘change over time’, ‘development’, ‘differen*’, ‘discriminat*’, ‘test*’, ‘intervention’, ‘season’, ‘preseason’, ‘repeat’, ‘assess*’, ‘evaluat*’, ‘yo-yo’, ’30-15’, ‘rugby league’, ‘sprint’, ‘jump’, ‘aerobic’, ‘anaerobic’, ‘intermittent’, ‘strength’, ‘power’, ‘cmj’, ‘agility’, ‘cod’, ‘change of direction’, ‘force’, ‘speed’, ‘physical quality*’, ‘physical characteristics’, ‘body composition’, ‘anthropometry’. These combinations were searched using four levels. For example, ‘change’ OR ‘change over time’ [additional terms] AND ‘test’, OR ‘intervention’ [additional terms] AND ‘rugby league’ AND ‘sprint’ OR ‘jump’ [additional terms]. Additional studies were identified by examination of ‘in-press’ publications across related journals, reference lists of all papers included, and examination of similar review articles. The full search process is outlined in Figure 2.

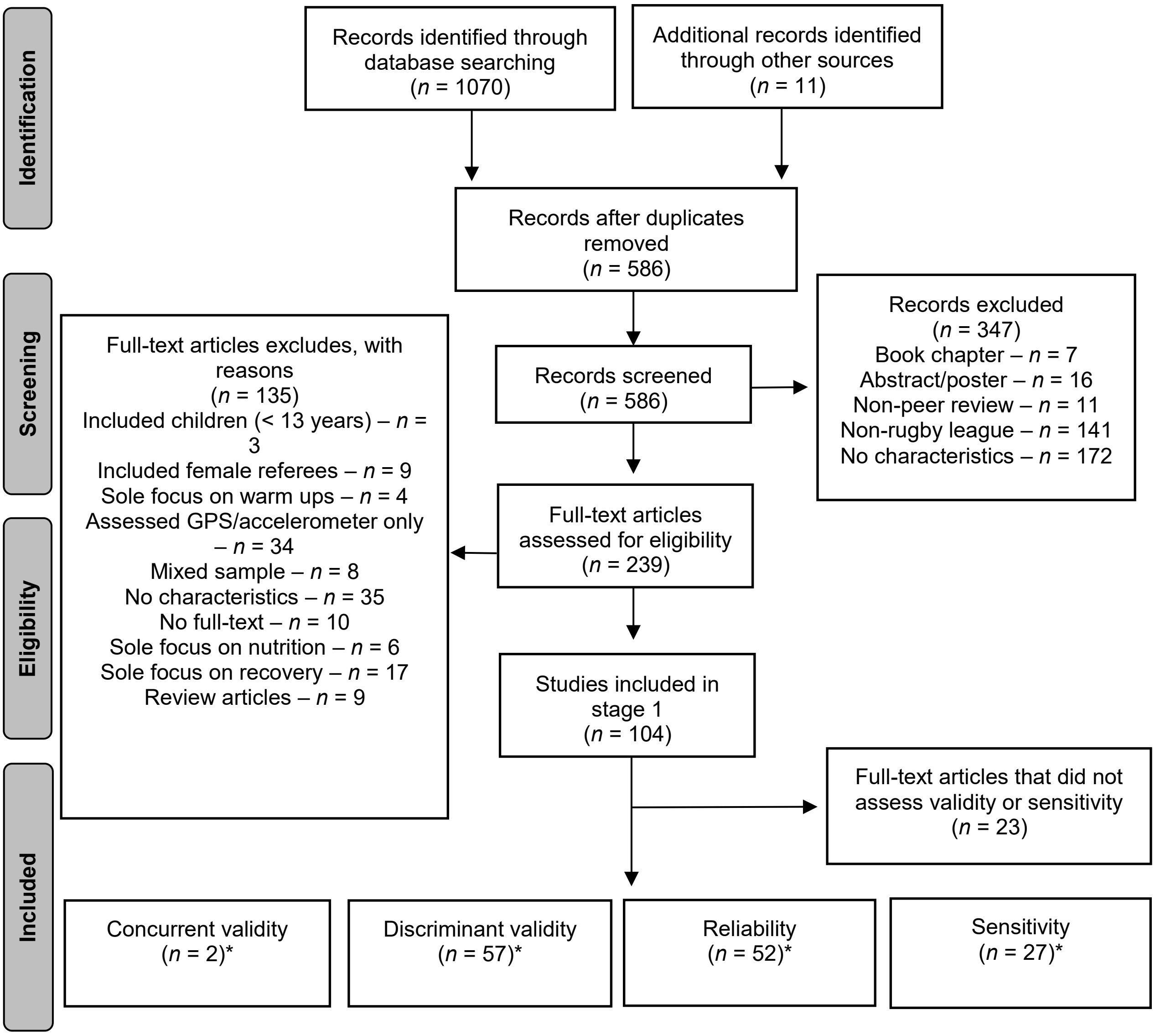

Figure 2. PRISMA flow diagram of study search criteria.

** indicates the study could have included multiple measurement property categories.*

2.2.3. Eligibility criteria

Studies were included if they met the following criteria: 1) written in English, 2) full-text was available, 3) included male rugby league players who were considered youth/junior, academy and senior, 4) was an original article, 5) used at least one test of anthropometry or physical characteristics, and 6) assessed either the concurrent validity, discriminant validity, sensitivity and/or reliability.

2.2.4. Exclusion criteria

Once all duplicates were removed using EndNote (X8, Thomson Reuters, Philadelphia, USA), the title and abstract of all studies were reviewed. As this study's aims are two-fold, the exclusion of published literature was conducted in two stages (see Figure 2). Initially, all book chapters, abstracts, posters, non-peer review articles or research that did not include rugby league players were excluded. The remaining full-text articles were read in full and excluded if they: 1). Did not include a measure of anthropometry or physical characteristic, 2). Assessed GPS or accelerometer data only, 3). Solely focused on recovery, 4). Were review articles or commentaries, 5). Focused on females and/or referees, 6). Solely focused on nutrition, 7). Focused on warm-ups, 8). Were based on children below the age of 13 years. The final stage sub-divided full-text articles into those reporting concurrent validity, discriminant validity, reliability and/or sensitivity.

2.2.5. Data extraction

The following data were captured: publication details (authors and publication year), participant details (age, playing standard, country, sample size), and the anthropometric and physical characteristics assessed along with the corresponding test (name, brief procedures, reliability). To determine the validity and sensitivity, the researcher also extracted details on the study design, statistical methods used and for sensitivity only, details on the training or season completed (i.e. frequency, duration, intensity). A risk of bias quality scale was not utilised in this systematic review given the difficulties in applying a validated scale across many study types (i.e. pre-posttest, case study, cross-sectional etc.).[162,197] Further, as most of the research included in this systematic review is applied in nature, the notion of blinding participants and researcher/practitioners is highly impractical and difficult to implement. Finally, as this review aims to document the performance tests used across rugby league with reference to validity, reliability and sensitivity as opposed to determining the practically or clinically meaningfulness of an independent variable on the dependent variable (i.e. meta-analysis), and that no studies would be omitted regardless of score, the researcher opted not to include an assessment.[139,165] However, in relation to this issue, a previous systematic review[43] that has investigated the measurement properties of physiological tests across rugby (league and union) suggest that studies tend of be of a low to fair quality. It is, therefore, important to consider this when interpreting the results of the literature included. This is particularly pertinent for those assessing changes in anthropometric and physical characteristics where results could be subject to biases as well as misleading conclusions due small samples sizes and methodological issues (i.e. lack of control group and poor procedural description).

2.3. Results

2.3.1. Search results

Initial searchers yielded 1070 academic sources with 586 screened and 239 undergoing a detailed review for eligibility (Figure 2). During stage 1, data was extracted from 104 articles that met the inclusion criteria 1 to 7 and assessed the anthropometric and/or physical characteristics of male rugby league players. Application of inclusion criteria 7 resulted in 81 studies taken forward that reported one or more measurement properties.

2.3.2. Description of included studies

The general characteristics of the studies included at both stages of the search are presented in Table 1. The majority of studies were based in Australia (54/104; 52%) and England (41/104; 39%), with a further two being conducted in France (1.9%); one in New Zealand (0.9%); one in Croatia and Slovenia (0.9%); and one including both Australian and English players (0.9%). Four studies did not report the location in which they were conducted (3.9%). The studies varied in research design and included retrospective, experimental, longitudinal, case study, cohort and cross-sectional investigations. Participants included in the studies ranged from amateur through to professional and included junior, academy and senior players (Table 1).

2.3.3. Anthropometric and physical characteristics

Studies that assessed the anthropometric and/or physical characteristics of male rugby league players are presented in Table 2. This review identified 38 anthropometric and 16 unique physical characteristics evaluated among youth, academy and senior rugby league players (Table 2). Furthermore, the review highlighted that many tests or combinations of tests are available for assessing similar characteristics in the 'field' or alternative (i.e. laboratory) settings (Table 3, Page 96), with some variance between studies regarding the testing procedures and dependent variables used.

Table 1. Summary of literature included in this systematic review.

Author	*n*	Population	Study design	Country	Characteristics
Atkins (2004)[6]	54	Academy, semi-professional & professional	Cross-sectional	England	Stature, body mass, whole-body strength
Atkins (2006)[5]	50	Semi-professional & professional	Cross-sectional	England	Stature, body mass, prolonged high-intensity intermittent running
Austin et al. (2013)[10]	12	Senior professional	Cross-sectional	Australia	Repeated effort ability, prolonged high-intensity intermittent running, linear sprint speed
Babic et al. (2001)[11]	111	Unknown	Cross-sectional	Croatia & Slovenia	Stature, body mass, BMI, %BF, FM, FFM, somatotype
Baker (2001)[14]	49	Amateur and professional	Cross-sectional	Australia	Stature, body mass, upper-body strength, upper-body power
Baker (2003)[16]	46	Senior professional	Cohort	Australia	Stature, body mass, upper-body strength, upper-body power.
Baker & Nance (1999)[15]	20	Senior professional	Cohort	Australia	Stature, body mass, upper-body strength, lower-body strength, whole-body strength
Baker (2009)[18]	64	Senior professional	Cohort	Australia	Stature, body mass, upper-body strength, strength endurance,
Baker (2013)[17]	6	Senior professional	Longitudinal	Australia	Stature, body mass, upper-body strength, upper-body power,
Baker (2017)[21]		Senior professional	Cohort	Australia	Stature, body mass, upper-body strength, lower-body strength.
Baker & Newton[20]	34	Semi-professional & professional	Cross-sectional	Australia	Height, weight, upper-body strength
Baker & Newton[19]	42	Professional	Within- and between-subject experimental	Australia	Height, body mass, upper-body strength, upper-body power
Baker & Newton[12]	12	Amateur, semi-professional, professional	Cross-sectional	Australia	Height, body mass, upper-body strength, strength endurance, upper-body power
Baker & Newton[13]	40	Semi-professional & professional	Cross-sectional	Australia	Height, body mass, lower-body strength, lower-body power, running momentum, linear speed, change of direction ability

Ballard[22]	113	State, national & professional	Cross-sectional	Australia	Body mass, body composition, linear speed, estimated VO_{2max}, upper-body strength, lower-body strength,
Brown et al.[30]	32	Senior professional	Cohort	Australia	Height, body mass, lower-body strength, BMI
Cheng et al.[41]	116	Academy	Cross-sectional	Australia	Stretch stature, body mass, BMI, body composition, anthropometrics, somatotype
Clark et al.[45]	8	Semi-professional	Cross-sectional	Australia	Height, body mass, upper-body strength, upper-body power,
Cobley et al.[46]	595-683	Youth	Longitudinal		Height, sitting height, body mass, skinfold thickness, lower-body power, upper-body power, linear speed, change of direction time, estimated VO2max
Comfort[52]	12	Senior professional	Cohort	England	Height, body mass, whole-body power
Comfort et al.[49]	16	Senior professional	Cohort	England	Height, body mass, whole-body power
Comfort et al.[48]	11	Senior professional	Cohort	England	Height, body mass, whole-body power
Comfort et al.[51]	18	Senior professional	Cohort	England	Height, body mass, linear speed, change of direction ability, lower-body power, lower-body strength, whole-body strength
Comfort et al.[46]	19	Semi-professional	Cohort	England	Height, body mass, lower-body strength, linear speed,
Comfort et al.[50]	15	Senior professional	Cohort	England	Height, body mass, body composition, lower-body strength, whole-body power, lower-body power, linear speed, running momentum,
Coutts et al.[54]	7	Academy	Cohort	Australia	Body mass, BMI, estimated VO2max, lower-body strength, upper-body strength, strength endurance, linear speed, lower-body strength, lower-body power
Cross et al.[56]	16	Senior professional	Cohort	New Zealand	Height, body mass, linear sprinting properties
Darrall-Jones et al.[61]	14	Senior professional	Cross-sectional	England	Linear speed
De Lacey et al.[65]	39	Senior professional	Cohort	Australia	Height, body mass, linear speed, linear sprinting properties, lower-body strength,
Delaney et al.[69]	31	Senior professional	Cohort	Australia	Height, body mass, skinfold thickness, linear speed, change of direction ability, lower-body power, reactive strength, lower-body strength
Delaney et al.[68]	22	Senior professional	Cohort	Australia	Height, body mass, body composition
Dos Santos et al.[76]	9	Academy	Cohort	England	Stature, body mass, whole-body strength
Dos Santos et al.[78]	30	Academy	Cohort	England	Stature, body mass, whole-body strength
Gabbett & Benton[88]	66	Senior amateur & professional	Cross-sectional	Australia	Agility

Gabbett et al.[111]	86	Senior amateur	Pre-Posttest	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett, Kelly & Pezet[105]	98	Senior amateur	Cross-sectional	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett et al.[106]	64	Academy	Cohort	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett[108]	35	Senior amateur	Cohort	Australia	Height, body mass, body composition, lower-body power, linear speed, estimated VO_{2max}
Gabbett[94]	151	Senior amateur	Cross-sectional	Australia	Body mass, linear speed, lower-body power, change of direction ability, estimated VO_{2max}
Gabbett[115]	66	Senior semi-professional	Cohort	Australia	Body mass, linear speed, lower-body power, change of direction ability, estimated VO_{2max}
Gabbett[96]	240	Academy	Cross-sectional	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett[97]	68	Senior amateur	Longitudinal	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett[118]	45	Senior amateur	Longitudinal	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett[123]	69	Senior amateur	Cohort	Australia	Speed, change of direction, lower-body power, estimated VO_{2max}
Gabbett[99]	415	Senior amateur	Cross-sectional	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett[116]	77	Senior amateur	Cohort	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett[109]	88	Senior amateur	Cross-sectional	Australia	Height, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett[120]	12	Senior professional	Correlational	Australia	Height, body mass, body composition, lower-body power, upper-body power, acceleration speed, linear speed, change of direction ability.
Gabbett[114]	11	Senior semi-professional	Correlational	Not reported	Body mass, linear speed, upper-body strength, muscle endurance, estimated VO_{2max}
Gabbett & Domrow[89]	183	Amateur	Cohort	Australia	Stature, body mass, body composition, linear speed, lower-body power, change of direction ability, estimated VO_{2max}
Gabbett et al.[119]	41	Youth	Correlational	Australia	Stature, body mass, body composition, linear speed, change of direction ability, lower-body power

Gabbett et al.[121]	58	Senior professional	Cohort	Australia	Stature, body mass, body composition, linear speed, change of direction ability, lower-body power, repeated sprint ability, prolonged high-intensity intermittent running, estimated VO_{2max}
Gabbett et al.[104]	86	Senior professional	Cohort	Australia	Stature, body mass, body composition, linear speed, change of direction ability, lower-body power, repeated sprint ability, prolonged high-intensity intermittent running, estimated VO_{2max}
Gabbett et al.[112]	37	Senior semi-professional & professional	Correlational	Australia	Stature, body mass, body composition, linear speed, lower-body power, change of direction ability
Gabbett et al.[117]	35	Youth & Academy	Pre-posttest	Australia	Stature, body mass, body composition, linear speed, change of direction ability, lower-body power, estimated VO_{2max}
Gabbett et al.[124]	42	Senior professional	Cross-sectional	Australia	Linear speed, change of direction ability, reactive agility
Gabbett & Seibold[92]	32	Senior professional	Correlational	Australia	Body mass, upper-body strength, lower-body strength, strength endurance, lower-body power, prolonged high-intensity intermittent running
Gabbett et al.[113]	66	Senior professional	Cross-sectional	Australia	Stature, body mass, body composition, linear speed, lower-body power, upper-body power, upper-body strength, lower-body strength, whole-body power, strength endurance, repeated sprint ability, prolonged high-intensity intermittent running, estimated VO_{2max}
Georgeson et al.[127]	37	Senior professional	Longitudinal	Australia	Height, weight, body composition, balance, lower-body power
Harley et al.[133]	20	Senior professional	Longitudinal	England	Stature, body mass, body composition
Harris et al.[134]	18	Senior professional		Not reported	Stature, body mass, lower-body strength, linear speed
Hulin et al.[154]	32	Senior professional	Correlational	Australia	Body mass, prolonged high-intensity intermittent running
Ireton et al.[160]	55	Youth, academy & senior professional	Cross-sectional	Youth	Stature, body mass, whole-body strength, lower-body power, movement competency
Johnston et al.[164]	12	Unknown	Randomised counterbalanced cross-over experimental	Not reported	Stature, body mass, repeated sprint ability, repeated effort ability

Johnston et al.[169]	21	Academy	Between-group, repeated measures design	Australia	Height, body mass, prolonged high-intensity intermittent running, lower-body strength, upper-body strength
Jones et al.[175]	113	Senior professional and semi-professional	Cross-sectional	England	Stature, body mass, body composition
Jones et al.[174]	3	Academy	Case study	England	Height, body mass, lower-body power, linear speed, running momentum, upper-body strength, lower-body strength, prolonged high-intensity intermittent running
Jones et al.[176]	12	Senior professional	Cross-sectional	England	Stature, body mass, body composition
Kirkpatrick & Comfort[179]	24	Academy	Cross-sectional	England	Stature, body mass, lower-body power, linear speed, upper-body strength, lower-body strength
McMahon et al.[187]	34	Academy & Senior professional	Cross-sectional	England	Stature, body mass, lower-body power
McMahon et al.[188]	21	Senior Professional	Correlational design	England	Height, body mass, lower-body power
Meir et al.[189]	146	Senior Professional	Cross-sectional	Australia & England	Body mass, body composition, upper-body strength, lower-body strength, linear speed, strength endurance, endurance, change of direction ability
Morehen et al.[198]	112	Senior Professional	Cross-sectional	England	Height, body mass, body composition
Morgan & Callister[200]	57	Senior semi-professional	Pre-posttest	Australia	Height, body mass, body composition
Morley et al.[202]	84	Youth	Cross-sectional	England	Height, sitting height, body mass, linear speed, lower-body power, upper-body power, change of direction ability, movement competency
Pearce et al.[209]	174	Academy & Senior Professional	Cross-sectional	Australia	Height, body mass, lower-body power, linear speed, repeated sprint ability, change of direction ability, prolonged high-intensity intermittent running, movement competency.
Rivière et al.[213]	16	Academy	Pre-posttest	France	Height, body mass, upper-body strength, upper-body power
Sayers[217]	15	Amateur		Not reported	Height, body mass, linear speed, change of direction ability
Scott et al.[219]	55	Youth & Academy	Test-retest	Australia	Height, body mass, body composition, prolonged high-intensity intermittent running
Scott et al.[220]	63	Academy & Senior Professional	Cross-sectional	Australia	Body mass, body composition, estimated VO_{2max}, endurance, linear speed, change of direction ability, prolonged high-intensity intermittent running, VO_{2max}, repeated sprint ability.

Seitz et al.[222]	24	Academy	Pre-posttest	Australia	Height, body mass, linear speed
Seitz et al.[221]	10	Academy	Pre-posttest	France	Height, body mass, prolonged high-intensity intermittent running, linear speed, repeated sprint ability
Slater et al.[227]	20	Professional		Australia	Height, sitting height, body mass, body composition
Speranza et al.[232]	24	Semi-professional	Correlational design	Australia	Upper-body power, lower-body power, upper-body strength, upper-body strength
Till et al.[256]	81	Youth	Longitudinal	England	Height, sitting height, body mass, body composition, lower-body power, upper-body power, linear speed, change of direction ability, estimated VO_{2max}
Till et al.[241]	580	Youth	Cross-sectional and longitudinal	England	Height, sitting height, body mass, body composition, lower-body power, upper-body power, linear speed, change of direction ability, estimated VO_{2max}
Till et al.[243]	1172	Youth	Longitudinal	England	Height, sitting height, body mass, body composition, lower-body power, upper-body power, linear speed, change of direction ability, estimated VO_{2max}
Till et al.[250]	81	Youth	Longitudinal	England	Height, sitting height, body mass, body composition, lower-body power, upper-body power, linear speed, change of direction ability, estimated VO_{2max}
Till et al.[242]	580	Youth	Cross-sectional	England	Height, sitting height, body mass, body composition, lower-body power, upper-body power, linear speed, change of direction ability, estimated VO_{2max}
Till et al.[251]	1172	Youth	Longitudinal	England	Height, sitting height, body mass, body composition, lower-body power, upper-body power, linear speed, change of direction ability, estimated VO_{2max}
Till et al.[244]	61	Academy	Longitudinal	England	Height, body mass, body composition, linear speed, running momentum, prolonged high-intensity intermittent running, upper-body strength, lower-body strength, lower-body power
Till & Jones[240]	121	Youth	Longitudinal	England	Height, sitting height, body mass, body composition, lower-body power, upper-body power, linear speed, change of direction ability, estimated VO_{2max}
Till et al.[252]	65	Youth and Academy	Longitudinal	England	Height, body mass, body composition, linear speed, running momentum, prolonged high-intensity intermittent running, upper-body strength, lower-body strength, lower-body power

Till et al.[253]	75	Youth and Academy	Longitudinal	England	Body mass, body composition, linear speed, running momentum, lower-body power, prolonged high-intensity intermittent running, upper-body strength, lower-body strength
Till et al.[246]	81	Youth and Academy	Cross-sectional	England	Height, body mass, body composition, linear speed, running momentum, prolonged high-intensity intermittent running, upper-body strength, lower-body strength, lower-body power
Till et al.[247]	257	Youth	Longitudinal	England	Height, body mass, body composition, linear speed, lower-body power, upper-body power, change of direction ability, estimated VO_{2max}
Till et al.[254]	51	Youth	Cross-sectional	England	Height, sitting height, body mass, body composition, linear speed, lower-body power, upper-body power, change of direction ability, estimated VO_{2max}
Till et al.[256]	133	Youth and Academy	Longitudinal	England	Height, body mass, body composition, linear speed, lower-body power, lower-body strength, upper-body strength, estimated VO_{2max}
Till et al.[249]	683	Youth and Academy	Longitudinal	England	Height, body mass, body composition, linear speed, lower-body power, upper-body power, change of direction ability, estimated VO_{2max}
Tredrea et al.[257]	160	Youth and Academy	Longitudinal	Australia	Stature, sitting height, body mass, body composition, linear speed, estimated VO_{2max}, strength endurance, lower-body power
Waldron et al.[260]	13	Academy	Longitudinal	England	Stature, body mass, linear speed, lower-body power, lower-body strength, upper-body strength
Waldron et al.[265]	13	Youth	Longitudinal	England	Stature, sitting height, body mass, anthropometry , lower-body power, linear speed, estimated VO_{2max}
Waldron et al.[262]	36	Youth and Academy	Longitudinal	England	Stature, body mass, estimated VO_{2max}
West et al.[267]	39	Senior professional	Cross-section	England	Height, weight, upper-body strength, lower-body strength, whole-body strength, anthropometry, lower-body power, linear speed, repeated sprint ability.

Notes: BMI = body mass index, %BF = percentage body fat, FM = fat mass, FFM = fat free mass, VO_{2max} = maximal oxygen uptake.

2.3.3.1. Anthropometric characteristics

Almost all studies included in stage 1 reported the stature/height (76.9%) and body mass/weight (80.8%), with these terms used interchangeably. Whilst the use of different equipment is inevitable, it is important to standardise the measurement procedures to allow comparison across studies and to ensure that measures of performance such as running momentum, which uses body mass in its calculation, is accurate. In most instances, stature and body mass were reported as being measured to the nearest 0.1 cm and 0.1 kg, respectively, from a single measurement with few other details provided. One study measured stature to the nearest 0.5 cm[104] and another used the average of two measurements.[133] The procedures for measuring body mass included participants being measured in shorts,[160,174,198,245-248,252-254,256] socks, shorts and t-shirt,[190] fully clothed,[94] or light clothing.[200] In two studies, the researchers measured body mass in shorts and socks, and subtracted the mass of these two items from total body mass,[262,264] whilst another study asked participants to empty their bladder before measurements were recorded.[91] With regards to stature, two studies ensured that participants were in the Frankfort plane,[160,209] though only a few studies documented if the stretch stature technique was used and that footwear was removed.[41,200,264] Using stature and body mass, five studies calculated body mass index (BMI). The use of BMI has several limitations when assessing sporting populations such as rugby league players.[126] For example, it was reported that only 53% of U13 and U15 players classified as overweight or obese using BMI actually possessed excess FM.[126] BMI is unable to distinguish between FM and FFM, which is important in rugby league where these athletes participate in regular strength training with the aim of increasing muscle and total body mass.[248]

Table 2. Physiological characteristics assessed with corresponding performance test.

Characteristic	Performance test	Reference
Anthropometry	Stature/height	6,5,10,11-22,30,41,45-52,54,56,62,64,68,69, 76,78, 89, 92,94,96,97,99,104-106,108-121, 123,124,127, 133,134,154,160,164,169,174-176,179,187-191, 198,200, 202,209,213,217,219-222,227,232,240-254,256,257,260,264,262,267
	Body mass/weight	6,5,11-22,30,41,45-52,56,64,68,69,76,78,89,92,94, 96,97,99,104,106,108,109,111-121,127,133,134, 154,160,174-176,179,187-189,198,200,202,209, 213,217,219,222,227,232,240-247,249-254,256, 257,260,262,264,267
	Body mass index	11,22,30,41,127
	Sitting height	46,222,227,240-244,250,251,254,264
	Relaxed bicep girth	41,120,264
	Contract biceps girth	41,121
	Calf girth	41,121,264
	Waist girth	120,200
	Gluteal girth	120,200
	Thigh girth	120,200
	Chest girth	120,200,264
	Forearm girth	120,200
	Head girth	120,200
	Neck girth	120,200
	Ankle girth	120,200
	Wrist girth	200
	Humerus breadth	41,120
	Femur breadth	41,120
	Humerus length	200
	Femur length	200
	4-site skinfold thickness	46,99,105,108,109,111,240-244,246,247,249-255, 256
	5-site skinfold thickness	6
	6-site skinfold thickness	200
	7-site skinfold thickness	22,41,50,68,69,89,97,104,106,112,113,116-121,220, 257
	9-site skinfold thickness	1200
	Lean mass index	68,69,220,227
	Fat mass – 2C	11,50,68
	Predicted fat free mass – 2C	11,68,227
	Predicted body fat percentage	11,41,68
	Fat mass – 3C	133,175,176,198,227

	Lean mass – 3C	[133,175,176,198,227]
	Arm fat mass	[175,176]
	Leg fat mass	[175,176]
	Leg lean mass	[175,176]
	Trunk fat mass	[175,176]
	Trunk lean mass	[175,176]
	Bone mineral content – 3C	[133,134,175,176]
	Somatotype	[11,41]
Linear speed sprint properties	10 m, 20 m sprint test	[10,174,245,240,252,253,256]
	5 m, 10 m, 20 m sprint test	[51,47,50,124,217]
	2 m, 5 m, 10 m, 20 m, 30 m sprint test	[56]
	10 m, 40 m sprint test	[13,54,65,108,114,121,104,113,220,257,260]
	10 m, 20 m, 40 m sprint test	[89,94,96,97,99,105,106,109,111,116-188,123,179,221]
	10 m, 30 m, 40 m sprint test	[22,69]
	10 m, 20 m, 30 m, 40 m sprint test	[115]
	5 m, 10 m, 20 m, 30 m, 40 m sprint test	[62]
	10 m sprint test	[104,112,267]
	10 m, 30 m sprint test	[134]
	20 m sprint test	[202,264]
	30 m sprint test	[210]
	10 m, 60 m sprint test	[247]
	10 m, 20 m, 30 m, 60 m sprint test	[46,241-244,249-251,254]
	5 m, 10 m sprint test	[120]
	15 m, 40 m sprint test	[189]
	Sprint properties	[56,65]
Change of direction speed / agility	Standardised agility test	[51]
	505 agility test	[46,104,109,117,119,121,217,220,247,249,254]
	L-Run	[96,97,99,105,106,111,116,118,123,124,189,209]
	Illinois agility test	[94,115]
	Zig-Zag test	[202]
	Agility test	[13]
	Modified 505 agility test	[120,124]
Reactive agility	Novel reactive agility test	[110,124]
Lower-body muscular strength	3 RM back squat	[15,22,54,69,92,167,232,260,267]
	1 RM back squat	[13,17,47,50,113,174,179,189,245,246,252,253,256]
	4 RM back squat	[114]

	1 RM hack squat	134
	Isometric squat	51
	Isokinetic dynamometry knee extension	30,51,54,65
	Isokinetic dynamometry knee flexion	30,51,54,65
	Isokinetic dynamometry hip extension	30
	Isokinetic dynamometry hip flexion	30
Reactive strength	Reactive strength index	69,188
Upper-body muscular strength	1 RM bench press	12,14,15,17,19,20,21,113,174,179,189,213,245,246, 252,253,256
	3 RM bench press	22,54,92,169,232,267
	4 RM bench press	114
	Bench press at 55% and 80% isometric peak force	45
	1 RM prone row	174,245,246,252,253,255
	1 RM weighted chin-up	20,113
	3 RM weighted chin-up	22,92
	4 RM weighted chin-up	114
Whole-body strength	Isometric mid-thigh pull	6,49,76,78,160,267
	Isometric squat	51
Lower-body muscular power	Loaded squat jump 40 kg, 60 kg, 80 kg, 100 kg	13,15
	Loaded squat 40 kg	51,69
	Unloaded squat jump	50
	Countermovement jump – no arm swing	46,51,160,169,174,179,187,188,202,232,241-254, 256,257,260,264,267
	Countermovement jump – arm swing	54
	Vertical (Sargent) jump	89,92,94,96,97,99,104-106,108,109, 112-114,116 121,123,127,209
	Unilateral hop	69
Upper-body muscular power	Bench throw 40 kg, 50 kg, 60 kg, 70 kg, 80 kg	12,17,113
	Consecutive bench press 20 kg, 30 kg, 40 kg, 50 kg, 60 kg, 70 kg	15
	Bench throw 20 kg	12
	2 kg medicine ball throw – seated	46,202,240-244,247,249-251,254
	3 kg medicine ball throw - overhead	120
	Bench press 35%, 45%, 65%, 75%, 85% 1RM	213
	Bench throw at 55% and 80% isometric peak force	45
	Plyometric push-up	169,232

Whole-body muscular power	3 RM power clean	15
	Power clean 60% 1RM	48,49,52
	Hang power clean 60% 1RM	49
	Mid-thigh power clean 60% 1RM	49
	Mid-thigh clean pull 60% 1RM	49
	1 RM power clean	50,113
	3 RM power clean from hang	15
Strength endurance	Bench press reps to failure 60 kg	12,18,113
	Bench press reps to failure 102.5 kg	18
	Bench press reps to failure 60% 1RM	18
	Unloaded bench press reps to failure	92
	Chin-ups reps to failure	54,114
	Triceps dips reps to failure	114
	30 s plyometric push ups	189
	60 s sit up test	189
	60 s chin-ups	257
	60 s press ups	257
Repeated sprint ability	12 x 20 m sprints on a 20 s cycle	113,164,220
	8 x 20 m sprint on a 20 s cycle	221
	6 x 30 m sprints on a 30 s cycle	209
	10 x 40 m sprints on a 30 s cycle	267
Repeated effort ability	12 x 20 m efforts on 20 s cycle; 1 tackle against shield; 3 s grapple	165
	3 x 20 m sprints and active recovery between each on 20 s cycle; 2 x tackles, with 10 m sprint to tackle and 2 m drive	10
	3 x 20 m sprints and active recovery between each on 20 s cycle; 5 x tackles, with 10 m sprint to tackle and 2 m drive	10
Aerobic capacity	VO_{2max} estimated from the multi-stage fitness test	22,46,54,89,94,96,97,99,104-106,108,109,111,113-118, 121,123,154,220,240-244,247,249-251,254,257,262,264
	VO_{2max} estimated from the Yo-Yo Intermittent Recovery Test	174,256
	Graded VO_{2max} test	220
	VO_{2max} estimated from the 30-15 Intermittent Fitness Test	220
Prolonged high-intensity intermittent running	Yo-Yo Intermittent Recovery Test Level 1	5,10,92,169,209,245,246,252,253
	30-15 Intermittent Fitness Test	219- 221
	12 s sprint-shuttle test	104,114,122

Endurance	2 km time trial	[220]
(maximal aerobic speed)	5 minutes run	[189]
Qualitative assessment of movement proficiency	Overhead squat	[160,209]
	Double lunge	[160,209,260]
	Single leg Romanian deadlift	[160,209]
	Press up x 30	[160,209,260]
	Pull ups x 10	[160]
	Balance	[127]
	20 m sprint	[202]
	Zig-zag change of direction test	[202]
	Countermovement jump	[202]
	Squat	[202,260]
	Superman	[260]
	Medicine ball throw	[260]
	Hop, stick and grip	[260]
	Shoulder mobility	[260]
	Active straight leg raise	[260]
	Rotary stability	[260]

Numerous studies included sitting height as part of their anthropometric assessment with these studies predominantly using junior athletes.[202,240-244,250,251,257,264] The inclusion of sitting height, combined with several other factors, can be used to determine the age that peak height velocity occurs and to predict maturation status.[194] The procedure for measuring sitting height was consistent across studies and required participants to be seated on a chair of known height or on the floor with their stature measured to the nearest 0.1 cm.

The measurement of segment girths, breadths and/or lengths occurred in four studies (4.1%). Girths were measured using a steel tape and included at least one site (i.e. head, chest, neck). Breadths were measured using spreading or small-bone callipers and included at least two sites.[41,120,200] Lengths were assessed in one study using sliding callipers and a range of sites. Two studies included in this review used International Society for Advancement Kinanthropometry (ISAK) procedures,[41,200] though only one study reported that the measurements were taken by ISAK accredited practitioner with intra-tester CV of 1.0%.[41] Two studies included did not report using standardised procedures by an accredited practitioner, nor did they report the acceptable limits of tolerance.[11,120] Cheng et al.[41] used the mean of two measurements unless this exceeded 1%, whereby a third measure was taken and the median value used. Similarly, Morgan and Callister[200] used the mean of two, or median of three, measures depending if these exceeded 2 mm. No information regarding number of measurements was provided in two studies.[11,120]

Between-group differences in stature and body mass have been established in numerous studies, reported as small to moderate and are known to be influenced by age-grade, maturation, playing position and playing standards. For girths, breadths and/or somatotype, significant differences exist between playing position[11,41] and between Polynesian and non-Polynesian players.[41] Furthermore, Gabbett[120] reported moderate to large differences in girths and trivial-to-large differences in breadths between best and worst tackles as determined using a 1-on-1 tackling drill. It was noted that waist (r = -0.79) and gluteal (r = -0.74) circumference were significantly related with tackling ability, whilst negative, non-significant relationships were also observed for flexed arm (r = -0.53), chest (r = -0.57), thigh (r = -0.62) and calf (r = -0.62) girth. In addition, a negative relationship was observed between tackling ability and endomorphic categorisation (r = -0.65). With regards to changes in anthropometric measures, few studies have reported the change in stature and body mass over a season or training period (5%). Across a season, stature appeared to remain largely unchanged in junior[118] and senior[89] amateur players with an increase of ~3 cm in professional senior players after a 10-week period.[227] Changes in body mass were variable across studies, with some studies reporting minimal change across the competitive season,[89,118,1342] and small positive (~1.5 kg) and negative (~-1.0 kg) changes across an 8-14 week period of training.[47,227]

In all, it is important that the measurement of stature and body mass are standardised in order to allow for comparisons between studies and playing groups. It is also essential to standardise the measurement of body mass where such measures are combined with linear sprint times to calculate running momentum. The measurement of sitting height appears worthwhile, particularly within youth athletes.[244,251] Measurement of anthropometric characteristics such as girths, breadths and lengths should be completed by ISAK accredited practitioners in accordance with ISAK guidelines with authors providing details on the reliability, number of measurements, use of mean or median and the acceptable level of tolerance.

Skinfold analysis was commonly used comprising 4-, 5-, 6-, 7- and 9-sites from which several components such as lean mass index (LMI), fat mass (FM), fat free mass (FFM) and percentage body fat (%BF) were calculated (Table 2). Five studies used Dual Energy X-ray Absorptiometry (DXA) enabling the estimation of whole-body and limb FM and LM as well as bone mineral content (BMC).[68,133,175,176,198] One study used bio-electrical impedance to estimate FM and FFM.[68] Across the literature that used skinfold analysis, the procedures were similar throughout with the biceps, triceps, subscapular, supraspinale, calf, abdomen, pectoral, iliac crest and mid-axilla thickness measured with Harpenden callipers. There was limited information provided on the number of measurements taken with one study using the mean of two measurements;[99] one using the median of three measurements;[264] and three studies using the mean of two measurements unless the differences exceeded 5%, where the median of three was used.[41,68] Only one study reported using an ISAK level one practitioner[41] with two others stating they used a trained anthropometrist.[68,69] Skinfold measurements were reported as absolute values and used to estimate LMI, FM, FFM and %BF. LMI was calculated in 5 studies (4.6%) using the equation: M/S^x where M is the log transformed body mass, S is the log transformed skinfold thickness and x represents the exponent for rugby union forwards (0.13) and backs (0.14). FM and FFM was calculated from the estimation of %BF using equations by Jackson and Pollock[161] or Siri.[225]

The ICC for skinfolds ranged between 0.95 to 0.99 and CV between 1.1% and 3.5%. Using DXA, FM possessed a CV of between 0.82 to 1.90%; LM, 0.52 and 1.0%; %BF, 0.82 and 1.90%; and for BMC, 0.52%. The concurrent validity of measures of anthropometry specific to the composition of an athlete has been assessed against skill performance including tackling (r = -0.08 to -0.68),[111,112,114,119] skill under fatigue (r = -0.60), passing accuracy (r = -0.49), and play-the-ball speed (r = -0.43).[111] Furthermore, measures were also related to playing experience (r = -0.18 to -0.40),[78,110] body mass (r = 0.29 to 0.93),[112,114,119] acceleration ability (r = -0.38 to -0.46),[112,114,1198] change of direction ability (r = -0.01 to 0.54),[69,112,119] muscle power (r = -0.27 to -0.45)[112,119] and intermittent running ability (r = ~-0.36).[220] Across the competitive season, changes in skinfolds (4- and 7-site), FM, LM and %BF have been observed with results generally supporting the notion that these are improved over preseason (i.e. 90.7 *cf.* 84.7 mm) through to mid-season (i.e. 84.3 mm). Thereafter, it appears skinfold thickness, FM and %BF increase between the middle and end of season (i.e. 13.92 *cf.* 14.49 kg).[89.97,118,133] Till et al.[252] and Waldron et al.[264] observed a small overall reduction in skinfold thickness as junior players progressed over a 3-4-year period. Studies exploring the changes in skinfold thickness, LMI, FM and FFM over a specific training period support the notion that training interventions appear effective albeit, further work to reinforce this is warranted. The extent to which these measures differentiated between ages, standards, positions, maturation status and starters/non-starters is presented in Figures 3, 4 and 5. Overall, results indicated that those playing at higher standards and players selected had lower skinfold thickness and greater muscle mass. The differences between ages and playing positions were highly variable, and early maturers had higher skinfold values.

Overall, these results indicate that anthropometric measures specific to the composition of an athlete is an important characteristic in rugby league. Such measures should be considered given the relationship with skill performance and that it can discriminate between playing groups. However, greater clarity is required when reporting the measurement of these characteristics to aid interpretation and comparisons across studies. Whilst DXA is recognised as the criterion method[68] and can provide estimations of BMC, skinfold analysis and the resulting dependent variables such as FM, FFM and LMI appear reliable and valid practical alternatives.

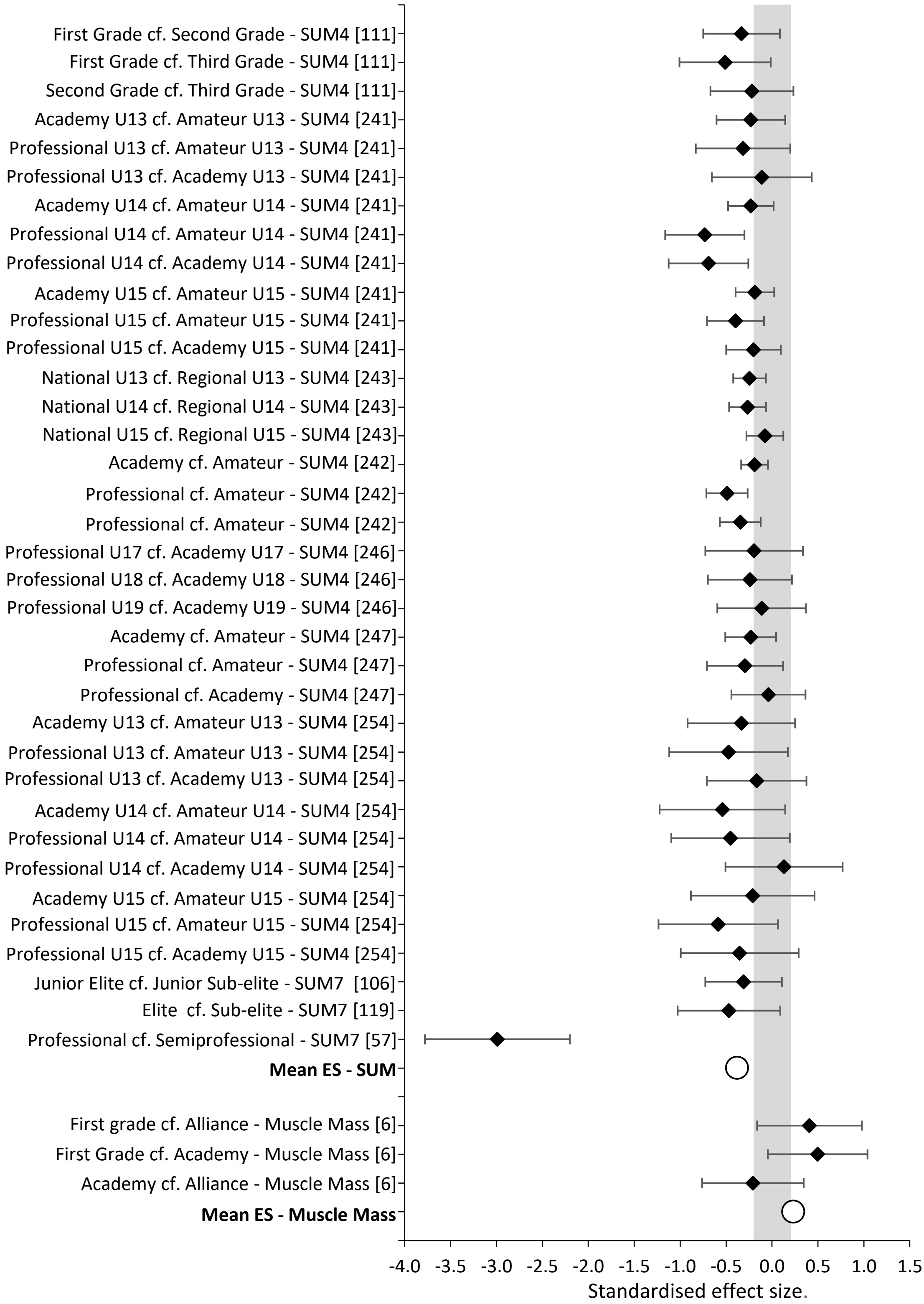

Figure 3. Mean effect size (± 90% CIs) between playing standards for skinfold thickness and muscle mass. SUM = sum of multiple skinfold sites. Open circles represent the mean effect size for each factor.

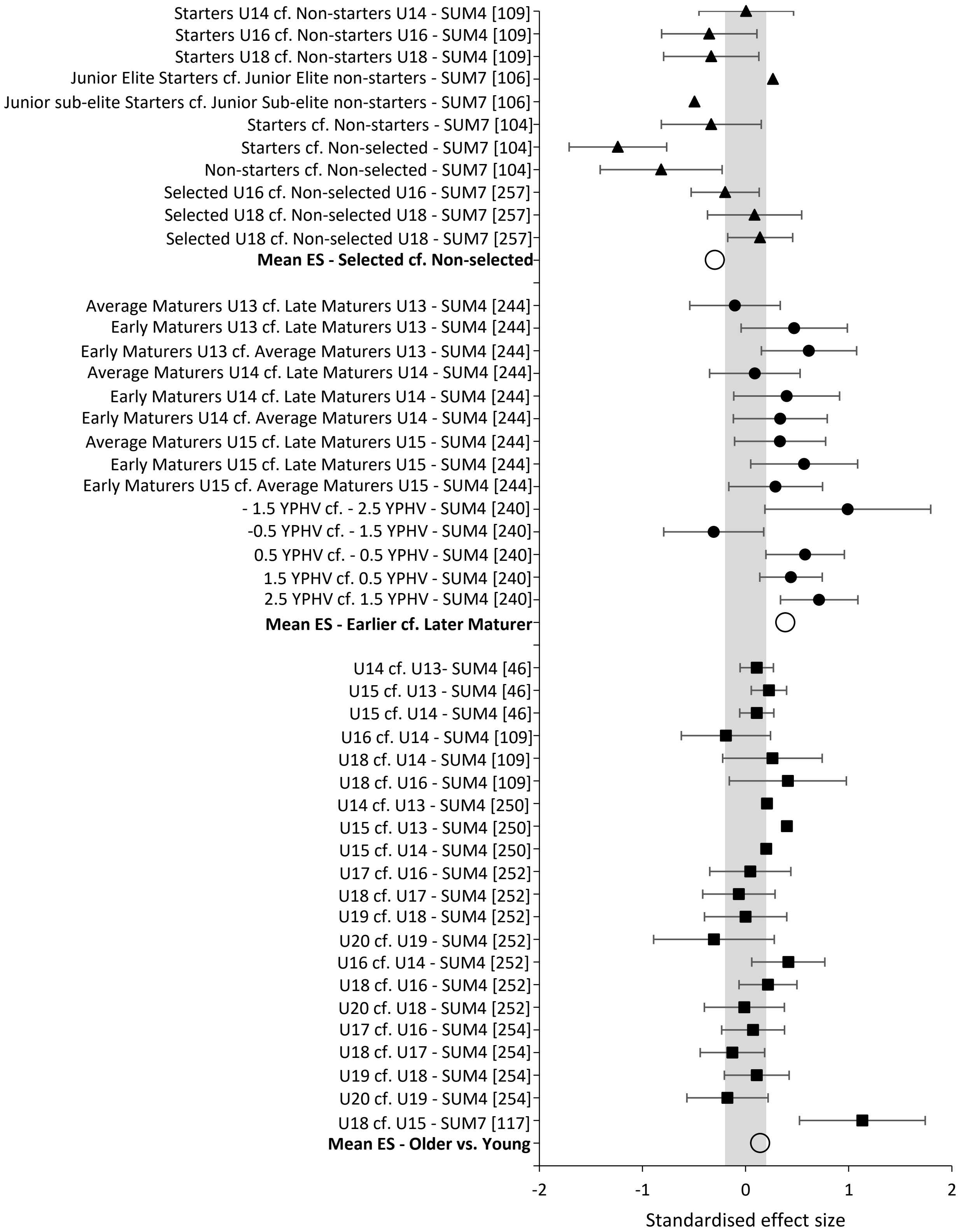

Figure 4. Mean effect size (± 90% CIs) between selected/non-selected (triangles) maturation statuses (circles) and age-groups (squares) for skinfold thickness. SUM = sum of multiple skinfold sites. YPHV = year at peak height velocity. Open circles represent the mean effect size for each factor.

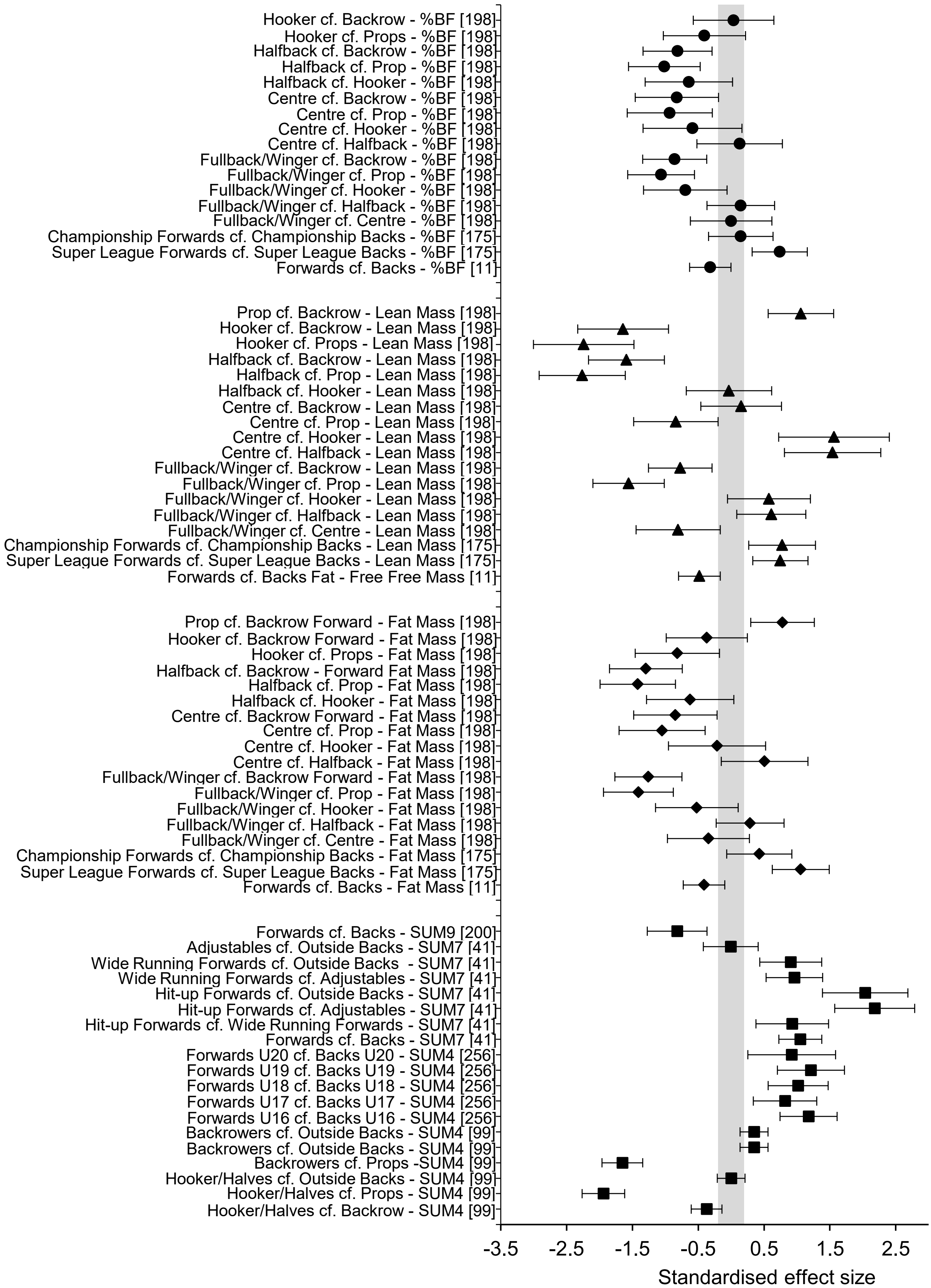

Figure 5. Mean effect size (± 90% CIs) between playing positions for skinfold thickness (squares), FM (diamonds), FFM and lean mass (triangles) and percentage body fat (circles). SUM = sum of multiple skinfold sites. %BF = body fat percentage.

2.3.3.3. Physical Characteristics

Linear sprint speed

The linear speed characteristics of rugby league players were assessed in 61% of studies included in this review, commonly measured over 10, 20, 30 or 40 m with some using 2 m, 5 m, 15 m and 60 m (Table 2). Almost all studies measured speed over multiple distances, with only 6 studies including a single measure of 10, 20 or 30 m.[112,121,202,209,264,267] Most studies that measured linear sprint speed simply reported sprint times in seconds, whilst 7 studies also reported the mean speed in meters per second.[22,69,104,112,120,121,220] Two studies explored the mechanical properties of sprinting performance on a non-motorised treadmill[65] and over-ground sprinting using validated field-based assessment.[56] Both methods provide greater detail into sprint mechanics and can support practitioners when prescribing training or managing return-to-play after injury.[191,201] Sprint times were measured using single- or dual-beam electronic timing gates with times recorded to 0.01 to 0.001 s albeit, the accuracy was not reported for 14 studies[13,22,47,50,51,65,104,105,113,134,179,209,221,267] A radar gun was used in two studies,[51,56] with the sampling frequency reported at 46.9 samples·s^{-1}.[56]

Whilst the assessment of linear speed is common, there are a number of methodological considerations that have been discussed previously[135] but warrant further comment here. Firstly, the starting distance from the initial timing gate varied between studies and included distances of 0, 0.2, 0.3, 0.5 m and 5 m. Thirty-five studies did not provide any details. Such procedures are important to consider when conducting an assessment of linear speed given a greater ‘flying start’ distance provides momentum and reduced the split times recorded.[137] For example, Haugen et al.[136] reported 20 m sprint times of 3.15, 3.07, 3.00, 2.94, 2.73, 2.58 and 2.51 s when participants started 0.5, 1.0, 1.5, 2.0, 5, 10, and 15 m, respectively, behind the initial timing gate. Due to these variances in start distance and issues this presents for comparing research, Haugen, Tønnessen and Seiler[136] have offered a correction factor depending on the 'flying start' distance that can be used for standardisation and ensure that sprint times are representative of those from a standing start at 0 m. Furthermore, few studies commented on the timing gate position with only 3 studies reporting the height of the timing gates,[54,260,264] which is known to influence sprint times,[55] and 18 studies noted the placement relative to wind (i.e. cross wind).[89, 96,97,99,105,106,109,111,112,114-118,120,123,189] Thirdly, the starting position of the athlete is an important consideration when conducting testing speed,[135] though only 7 studies reported a two-point athletic stance;[56,62,65,134,189,202,221] a further 24 reported a standing start with no detail on contact points; and 20 studies reported no details. Fourthly, the testing environment varied across studies and the data likely reflects the single club or international team approach. For example, 7 studies used an indoor track/court;[51,47,50,133,215,218,265] 3 studies used a turf track;[13,54,56] 5 studies used artificial turf;[103,111,112,120,178] 8 studies used natural grass;[96,99,107,109,120,189,257] and the remaining studies provided insufficient details to comment. The recovery time between sprints was not reported in 40% of studies and for those that did, values ranged between 1 and 5 minutes. Finally, few studies reported the number of sprints completed and whether the mean or peak values were used for analysis. Those that did, used between 2 and 3 sprints with the mean and peak used in 2 and 39 studies, respectively.

The reliability for tests of linear speed was reported in 67% of the studies with the ICC for 5, 10, 20, 30, 40 and 60 m reported at 0.80-0.98, 0.79-0.96, 0.78-0.99, 0.87-0.90, 0.89-0.97 and 0.92, respectively. The within-subject variations, typically expressed as a percentage (CV), were 2.0-3.2%, 1.1-8.4%, 1.1-4.5%, 2.0-3.3%, 1.2-1.9% and 2.3% for 5, 10, 20, 30, 40 and 60 m, respectively. The inclusion of the reliability properties is essential for the interpretation of results. No studies included in this review determined the reliability properties in accordance with the recommendations of Hopkins;[147] that is, using a sample of at least 50 athletes across three repeated trials conducted in the environment these tests will be carried out. Furthermore, only 4 studies (6.4%) in this review calculated a measure of a smallest or clinically meaningful change,[54,62,89,116] which were reported as 0.01-0.10 for 10 m; 0.02-0.04 for 20 m; 0.03 for 30 m and 0.04-0.10 for 40 m sprint times. With this in mind, future research in rugby league might seek to explore the reliability of linear speed using standardised testing procedures (i.e. two-point stance; 0.5 m 'flying start'; gate height at 60 cm; measured and reported to 0.01; on the same surface; cross wind etc.) and determine the change required to exceed the CV and smallest worthwhile change (SWC) in accordance the recommendations of Hopkins'.[146] Furthermore, consideration around how the SWC is determine with reference to linear sprinting in warranted. Previously, studies have used 0.2 multiplied by the CV to provide an estimate of SWC. However, whether this is suitable in all instances remains unknown or whether attention should be given to what the athlete, strength and conditioning coaches or skills coach believe is meaningful or what is meaningful in the context of the game (i.e. 0.03 quicker times could result in a meaningful reduction in passing time for the opponent).

The sensitivity of linear sprint speed has been explored across a specific intervention period;[123,134,221] a specific stage of the season (i.e. preseason);[50,54,116] across the entire season;[89,97,118,253,260] and across multiple seasons (Figure 6).[264] The pattern of change suggests acceleration and sprint ability improved from off-season through to mid-season, where thereafter, the effect size between off-season and the end of season is reduced. With regards to a training intervention, 8 to 9 weeks of training appears very effective, particularly when skill-based training was provided.

The concurrent validity of linear speed against match-play performance has not been reported in rugby league albeit, associations with tackling ability have been noted.[112,114,120] Research is required to explore if, and to what extent, linear sprint performance, as measured by time, speed or force-velocity properties, translates into on-field performance and injury risk.[1,82,228] The discriminant validity of linear sprint performance was explored in 37% of studies with these exploring differences between age-groups, playing positions, performance standards, training ages, maturity groups, starters/selected and non-starters/non-selected, and best and worst tacklers (Appendix 8).

Comparisons between groups suggests that measures of linear speed can discriminate between playing standards, with those athletes playing at a higher standard reporting quicker times than those at lower standards. There was high variability between playing positions and ages, though there was a trend for older players to be quicker than younger. Finally, those classified as early maturers and selected, out-performed those considered late maturers and non-selected, respectively. These results support the measurements of linear speed when assessing rugby players though future research should standardise measurement and report essential information for accurate interpretation. Furthermore, future research might consider exploring the mechanical factors that contribute to greater sprint times and whether these factors are associated with on-field performance (i.e. concurrent validity).

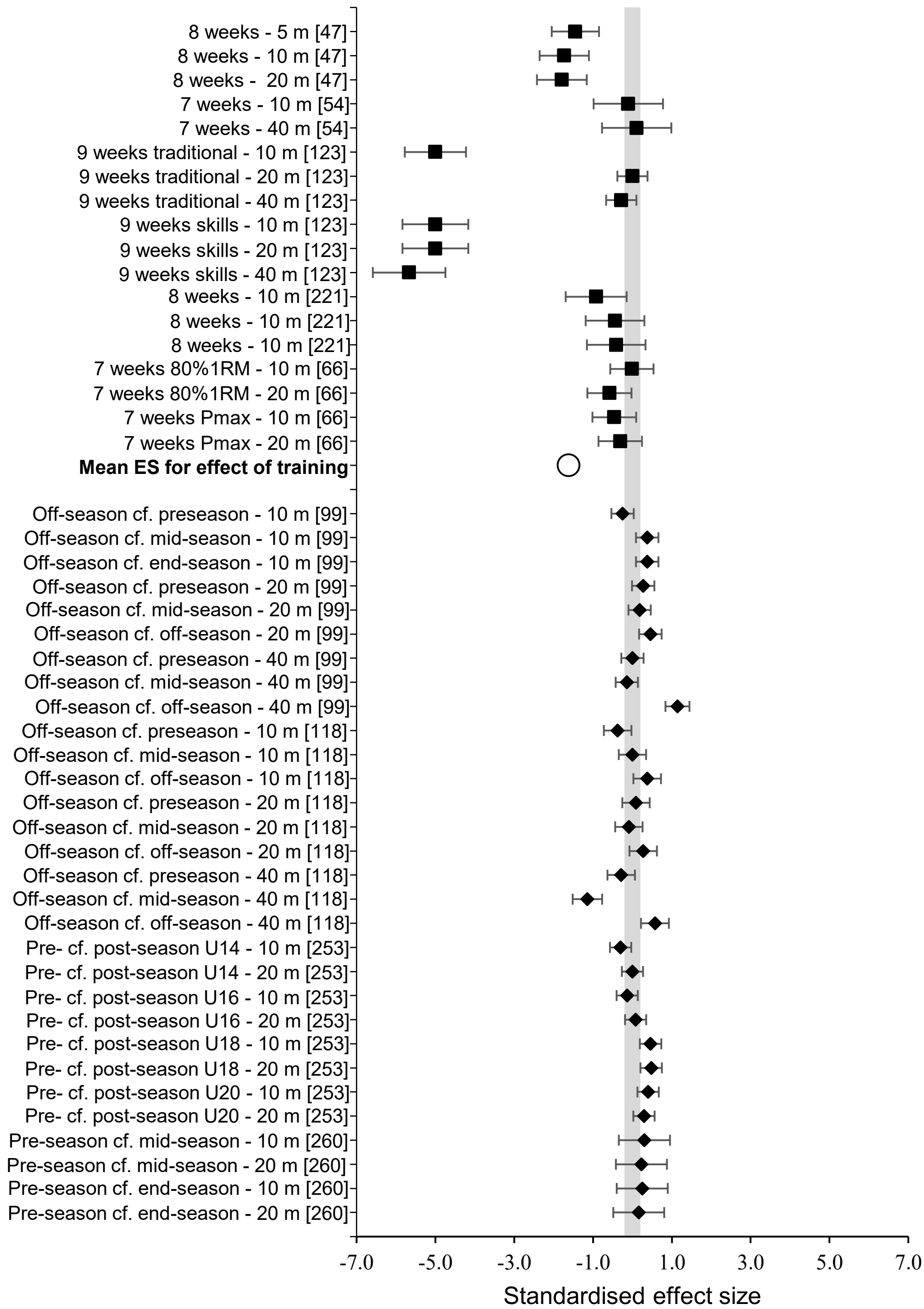

Figure 6. Mean effect size (± 90% CIs) for changes in sprint times across an intervention period/preseason (squares) or over a season (diamonds) and 1RM = 1 repetition max. Pmax = maximum power. Open circles represent the mean effect size for each factor.

3.3.2. Repeated sprint ability

Repeated sprint ability was reported in 6 studies (5.6%) using three individual tests. A repeated sprint test that involved 12 x 20 m sprints with 20 s recovery was used in four studies,[113,164,220,221] whereby players completed each 20 m shuttle as quickly as possible with a 20 s active recovery before completing the subsequent shuttle. In a separate study, a 6 x 20 m sprint test with 30 s recovery was used to evaluate the repeated sprint ability of academy and state rugby league players. Finally, West et al.[267] reported the baseline characteristics of their sample using a repeated sprint test that required players to complete 10 x 40 m shuttles with 30 seconds recovery. The tests used above reported the accumulative time to complete each sprint,[113,164,209,220,221,267] mean sprint time,[221] peak sprint time[221] and the percentage decrement[113,157,164,209,220] using the equation:

$$\text{Percentage decrement} = \frac{(\text{Total time} - (\text{lowest sprint time x no. sprints}))}{\text{Total time}} \text{ X } 100$$

The reliability of these tests has been reported using ICC values ranging from 0.91 and 0.96 for total time,[113,164] and 0.14 and 0.91 for percentage decrement,[113,164] with no data provided for mean or peak sprint times. The CV was reported at 1.5% (or 0.65 s) for total sprint time and ranged from 19.5 to 22.5% for percentage decrement in sprint times. Studies examining the validity of the RSA tests is currently limited. Pearce et al.[209] reported no differences in repeated sprint total time between U18, U20 and state-level players.[209] The concurrent validity between RSA and match-play has not been reported in rugby league, though the frequency of this activity is fairly limited during a game.[9,226] The sensitivity of the RSA test has been reported after a 10-week training intervention, whereby the authors noted significant improvements in mean sprint times, total sprint times and percentage decrement (ES = 0.27 to 6.48). It is also likely that a player's ability to perform any of the RSA tests and develop this characteristic can translate into other physical characteristics (i.e. VO_{2max} estimated from the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$) = r = -0.71).[220]

3.3.3. Lower-body power

The direct or indirect assessment of lower-body muscle power is common practice within rugby league with 57% of studies measuring this characteristic. The most common methods used were the CMJ with no arm swing (47.5%) and the vertical (Sargent) jump (40.7%). One study inferred lower-body power from a CMJ with an arm swing[54] whilst another study included a unilateral hop to explore left-right imbalances.[69] Unloaded or loaded jumps have also been used in five studies (8.5%) with one using a bar with no load,[50] two with a standardised 40 kg load,[51,69] and two studies measuring lower-body power across several loads.[13,15]

The procedures for the CMJ with and without arms varied across studies. For example, the majority of studies measured CMJ height using either a Just Jump System or vertical jump meter whilst a further 6 studies used a force platform with a sampling frequency between 500 and 1000 Hz. Further, of those using the CMJ technique, 64.2% did not specify any depths of squat; 7.0% strived for 90°; and the remaining 28.8% using a self-selected depth. Most studies provide insufficient details on the instructions given to participants and quality control procedures. Only 21.4% of studies reported checking at least one of the following: feet shoulder width apart; arms remaining on hips; legs remaining straight during flight (i.e. no knee tuck); flexing at the hip and knee before extending into the jump; and no pause at the bottom of the unweighting phase. The Just Jump System was used in 35.6% of studies though the validity of this has recently been questioned.[186] Another discrepancy across studies is the length of recovery between efforts. Whilst almost all studies use the peak value of 2 or 3 jumps, the length of recovery between these efforts ranged from 30 s to 180 s, with most (32.0%) using 60 s. Importantly, 11 studies did not report recovery length, 2 studies did not report how many jumps were completed, 8 studies did not report whether the mean or peak height was used, and 11 studies did not state the accuracy of data presented (i.e. 0.1 cm). Such findings highlight the need to provide a standardised set of reporting criteria in an attempt to make comparison across the literature including recovery, depth, instructions, equipment and any correction factors, reliability, number of jumps and outcome measures (i.e. mean or peak jump height, peak power, mean power).

In addition to the CMJ, the vertical jump was used in 40.7% of studies and involved players extending their arm and hand to get a measure of standing height. After assuming a crouched position, participants were then instructed to propel themselves upwards and touch a yardstick device (i.e. Vertec jump) at the highest possible point, with the differences used as jump height. The procedures for this test are fairly consistent across studies with few omissions or inconsistencies as this was largely used by the same research group. Nonetheless, not all studies included details on the recovery between vertical jumps, footwear or reliability statistics. In the only study to infer unilateral lower-body power, Delaney et al.[69] reported the distance achieved during a single-leg long jump. Participants completed 3 maximal efforts on each leg with free arm movement and the furthest distance used for analysis. In addition to distance, the left-right imbalance was calculated. A total of 5 studies assessed lower-body power using a loaded jump. Comfort et al.[50] used a squat jump to evaluate lower-body power using minimal load, whereby participants completed three repetitions with a bar load equivalent to the pull of a linear position transducer. Participants started at 130° knee flexion, lowered the bar, paused for 2 s at the bottom, and then extended upwards. Peak power was ascertained using a force plate (true calibration with participant on toes) and linear position transducer. The weighted squat jumps included a standard load of 40 kg (20 kg bar + load) with Comfort et al.[51] using a force plate and having participants complete 3 reps with 1-min rest; no information on whether peak or mean values was reported. In contrast, Delaney et al.[69] used the peak power from for three trials measured using a linear position transducer. The same procedures were followed by Baker and Nance,[15] and Baker and Newton[13] with these authors assessing lower-body power across loads of 40, 60, 80 and 100 kg and peak power from a linear position traducer as the outcome variable.

The reliability of jump height or peak power was reported in the majority of studies with 15 studies providing no such details. For jump height using a jump mat, the ICC and CV were 0.90 to 0.96 and 2.1 to 5.6%, respectively, with no studies reporting the SWC. Using a force plate, the ICC and CV for peak power was 0.81 to 0.95 and 3.5 to 5.0%, respectively. Power output derived from a linear position transducer possessed an ICC 0.92 to 0.98 and CV of 2.1 to 2.9%. The discriminant validity of measures of lower-body power was explored in 35.2% of studies across playing ages, standards, positions, and maturation status (Figure 7 and 8). Results indicated trivial to very large differences in indirect measures of lower-body power between playing ages, with older players outperforming younger players. Similarly, those at higher standards out-performed those at lower standards on the vertical jump. Selected players out-performed non-selected players and those playing in the adjustable and outside back positions out-performed forwards. The concurrent validity of measures of lower-body power against rugby league match-play were explored in one study where no significant association was observed with (r = -0.50), low-intensity (r = -0.50) and high-intensity (r = -0.51) distance, total number of collisions (r = -0.32) and number of repeated high-intensity efforts (RHIE) (r = -0.49) in semi-professional players.[92] Whilst controlling for playing position, the negative associations reported suggest that those with greater lower-body power covered less distance, number of collisions and RHIE. However, as the authors failed to provide positional characteristics and used forward and back groups with no consideration for specific positional demands, the association might not be truly reflective of the influence of lower-body power on on-field match loads. Whilst a non-significant negative association with the number of collisions was also noted, Gabbett and colleagues reported positive associations between lower-body power and tackling ability (r = 0.15 to 0.38).[112,120] Kirkpatrick and Comfort[179] reported lower-body power was associated with absolute (r = 0.42) and relative (r = 0.57) back squat strength which has been reported to influence on-field performance.[92]

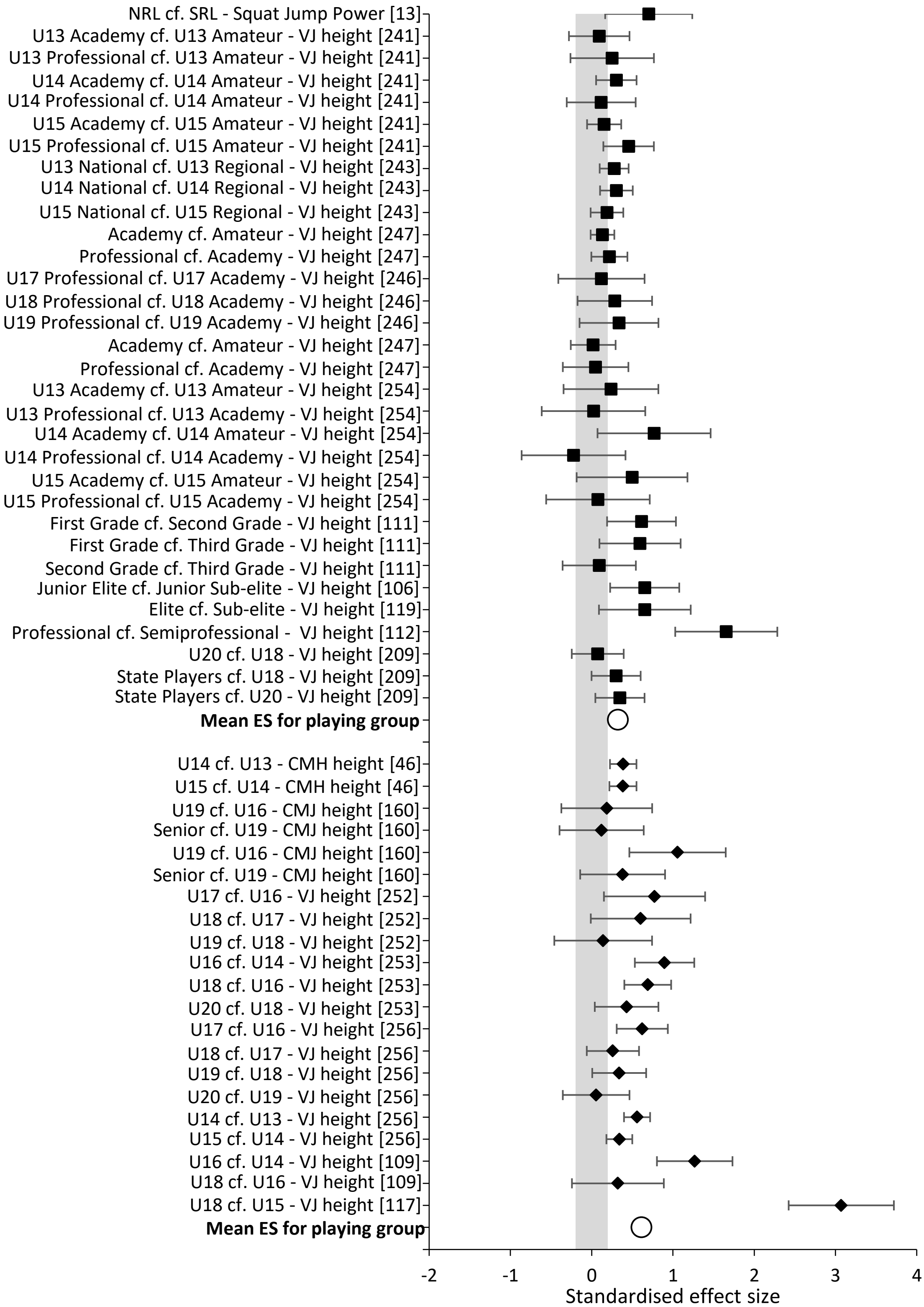

Figure 7. Mean effect size (± 90% CIs) between performance standards (squares) and age categories (diamonds) for direct or indirect measures of lower-body power. VJ = vertical jump. CMJ = countermovement jump. NRL = National Rugby League. SRL = State Rugby League. Open circle represents the mean effect size for each factor.

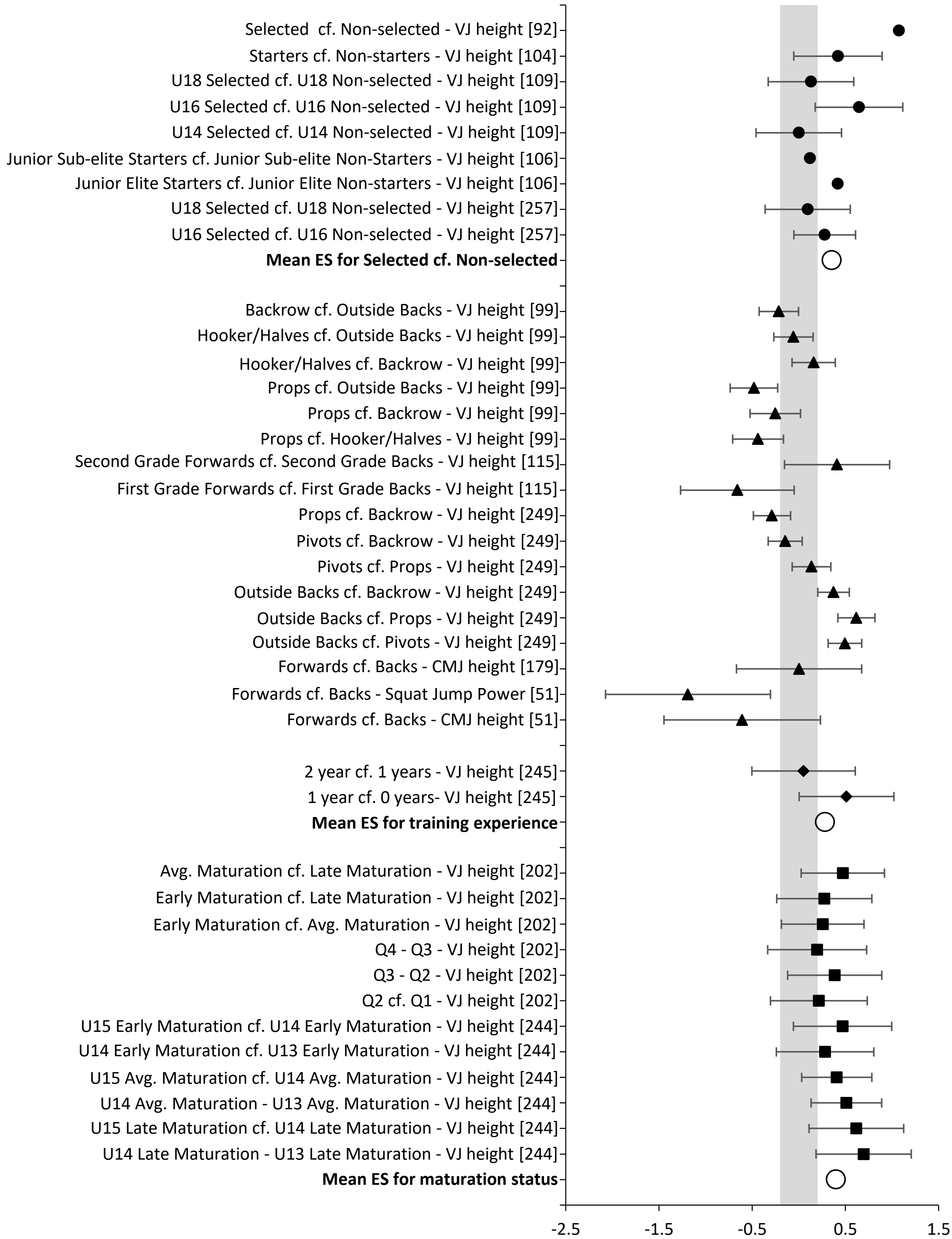

Figure 8. Mean effect size (± 90% CIs) in lower-body power between selected/non-selected (circles), positions (triangles), training experience (diamonds) and maturation status (square) for direct or indirect measures of lower-body power. Avg. = average. VJ = vertical jump. CMJ = countermovement jump. Q = quartile. Open circle represents the mean effect size for each factor.

3.3.4. Upper-body power

Upper-body power was inferred in 20.8% of studies with a number of tests used including a bench throw,[12,17,45,113] multiple-repetition bench press,[15,45] a seated[46,202,240-244,247,249-251,254] or overhead[120] medicine ball throw and a plyometric push-up.[169,232] Specifically, the bench throw procedures involved players throwing a barbell from a supine position using a single load (i.e. 20 kg);[12] across multiple loads (i.e. 40, 50, 60, 70 & 80 kg);[12,17,113] or loads corresponding to 55 and 80% of isometric peak force.[45] Similarly, bench press was executed in a supine position using a standard Olympic bar and with absolute (i.e. 20, 30, 40, 50, 60 and 70 kg) or relative (i.e. 35, 45, 65, 75 and 85% 1RM) loads. The seated medicine ball throw was used predominantly by a single research group[240-244,247,249-251,254] and required participants to be seated with their back against a wall and legs straight. From here participants pushed a 2 kg ball forwards striving for maximal distance. There was some variance in details reported across studies, but it can be assumed that total distance was measured from the wall to the point of landing, which is likely to overestimate the true distance from the point of release to the back of the landing imprint. Distance was measured to the nearest 0.1 cm or centimetre and required participants to complete 3 throws with the greatest distance used. Only one study included a practice throw;[249] two studies reported the inter-effort recovery of 60 s,[247,254] and the ICC and TE were 0.97 and 0.6%, respectively. For the overhead medicine ball throw, participants were required to throw a 3 kg medicine ball from a standing position and striving for maximal distance. Each throw was measured to the nearest centimetre from the start line to the nearest mark made by the ball with the furthest of three trials reported. ICC and CV for this test were 0.96 and 5.4%, respectively.

The concurrent validity of any of the measures noted above received minimal attention, with only one study reporting a negative relationship between upper-body using an overhead medicine ball throw and tackling ability. The discriminant validity was explored in a total of 13 studies with 11 of these using the seated medicine ball throw to determine differences between age categories,[46,249,250,254] playing standard,[241-2431,2475] playing position[249] and maturation status.[202,240,244,249] (Appendix 8). For the overhead medicine ball throw, those classified as 'worst tacklers' recorded greater distance than 'best tacklers' (9.9 m *cf.* 9.3 m), whilst the peak power output during the bench throw at loads of 40-80 kg was 597 ± 91 W, 558 ± 62 W and 493 ± 46 W for national, intrastate and intercity players, respectively.

The results above suggest that the seated medicine ball throw can discriminate between playing standards, maturation status, playing position and playing age, and could be a simple field-based alternative to infer upper-body pushing performance in rugby league players. However, the lack of research exploring the concurrent validity of all measures of upper-body power is a concern and may be a focus for future research.

3.3.5. Whole-body power

Whole-body power was inferred in 5 studies (4.7%) and required players to execute actions that included the combination of upper- and lower-body musculature. A total of 5 tests were noted across the literature that were deemed by the researcher to measure whole-body power (Table 2). These tests involved variation of a power clean, hang power clean or mid-thigh power clean with loads corresponding to 1RM, 3RM or a percentage of their 1RM (i.e. 60%). In brief, the power clean started with the bar positioned midway up the shin and caught in a shallow squat; the hang power clean with the bar positioned at the top of the patella and caught in a shallow squat; and mid-thigh power clean with the bar starting in-line with the middle of the thigh. The dependent variables from these assessments included both absolute load[15,113] and scaled loads,[50] as well as peak force, rate of force development[48,49,52] and peak power.[49,52] The ICC of the power clean, hang power clean and mid-thigh power clean were 0.86 to 0.98.[49,113] When specified for dependent variables, force during the power clean, hang power clean and mid-thigh power clean possessed an ICC of 0.88 to 0.97. For rate of force development, ICC was between 0.93 and 0.96. During the power clean, force, rate of force development and peak power possessed an ICC of between 0.96 and 0.99. No studies using a measure of whole-body power explored the discriminant validity or assessed the sensitivity of these tests. The concurrent validity for all measures of whole-body power against match-play has not been explored. The power clean is related to measures of strength and power such as 3RM bench press (r = 0.51), full squat (r = 0.79), jump squat (r = 0.79) and bench throw (r = 0.55) as well as acceleration times over 0-5 m (r = -0.47) and 0-10 m (r = -0.42). In all, further investigation is required to determine the usefulness of measures of whole-body power in rugby league including the reliability, validity and sensitivity of these tests. Furthermore, it is worth noting that the tests available to researchers and practitioners are limited to gym-based tests with no field-based alternatives.

3.3.6. Lower-body strength

Lower-body strength was evaluated in 29 studies (27.9%) and included the back squat, hack squat, isometric squat and isokinetic dynamometry (Table 2). The back squat was recorded at 1, 2 and 4RM, with procedures consistent across the studies.

In brief, participants were required to complete a warm up across a range of loads before executing the squat. In almost all instances, participants were required to squat to a depth that resulted in the thigh being parallel with the floor, when the crease of the hip was below the knee, or to a knee angle of 90°, which was standardised using a goniometer. There was a lack of detail across studies regarding the number of attempts and recovery, how the load was increased or decreased, and whether free weights or a power rack was used. One study used a 1RM hack squat that required participants to start with a knee angle of 110° verified using a goniometer with their feet positioned 5 cm apart.[134] One study used an isometric squat with the bar positioned on the trapezius at a height that corresponded with a knee angle of 135°. Participants completed three 3-seconds maximal efforts with peak force from across the 3 trials used. Finally, 4 studies include isokinetic dynamometry for their assessment of lower-body strength all reporting knee extensor and flexor peak torque and two reporting hip extensor and flexor peak torque. Four studies used an angular velocity of 1.05 radians per second or $60°\cdot s^{-1}$, whilst one study used 5.25 radians per second.[54]

The reliability was reported in a total of 7 studies with these restricted to the 1 and 3RM tests. A 1RM test yielded an ICC of between 0.93 and 0.97, and CV of 2.3%, which is similar to the 3RM (ICC of between 0.91 and 0.96, and CV of between 2.0 and 3.6%). The concurrent validity was determined for the 3RM squat test against match-play in a single study. Gabbett and Seibold[92] observed significant, positive correlations between 3RM and distance (r = 0.98), low-speed distance (r = 0.98), high-speed distance (r = 0.97) and number of repeated high-intensity efforts (r = 0.96) during a match for sub-elite players. Furthermore, the 1RM, 3RM or 4RM back squat has been associated with tackling ability in rugby league players[114,232] as well as a number of other physical characteristics such as acceleration and sprint (r = -0.247 to -0.68), change of direction (r = -0.21 to -0.28), bench press (r = -0.82), chin-up (r = 0.63), vertical jump (r = -0.54) and Yo-Yo IR1 (r = -0.14) performance.[50,69,92,127,1798,232,253] The discriminant validity was explored in 12 studies with these investigating differences between playing standards, positions, ages, and selected and non-selected players (Appendix 8). Those athletes playing at a higher performance standard consistently out-performed those at lesser standards as did those selected and those of higher age categories. The sensitivity of lower-body measures of strength was explored in 10 studies with a mean increase in 1RM of 30.2 kg after an 8-week preseason,[47] and increases of between 9 and 50 kg in 3RM after 7-8 weeks of training.[134,232] In contrast, no change was observed for the 3RM after 6 weeks of training and a 7-day taper in a small sample of state-level players, though improvements in isokinetic strength for the quadriceps and hamstrings at 5.25 radians per second was observed.[54] Across a season, improvements in 1 and 3RM ranged from 7.5 to 19.2 kg using junior rugby league players whilst over a 3- and 4-year period a mean increase in 1RM of 23.5 and 35.9 kg was observed, respectively.[246,252]

3.3.7. Upper-body strength

Upper-body strength was evaluated in 25.5% of studies and included the bench press, prone row or weighted chin-up. Studies using the bench press to measure upper-body strength included loads corresponding to the athlete's 1RM, 3RM and 4RM, and 55% and 80% of isometric peak force (Table 2). Six studies measured upper-body strength using a prone row, which required players to lay face down on a bench with height adjusted so that the participants' arms were in a locked-out position before pulling up the bar towards their chest.[1743,240,245,246,252,256] The weighted pull-up was used in 5 studies and involved the athlete performing a pull-up with additional mass attached to a lifting belt until 1RM, 3RM or 4RM was achieved (Table 2).

The reliability of the 1RM, 3RM and 4RM bench press was reported in 6 studies with ICC values of between 0.88 and 0.98, and CV values of between 1.5 and 2.6%.[12,17,54,92,113,232] No reliability properties were reported for the bench press at 55% and 80% peak isometric force, the 1RM prone row or the 4RM weighted chin-up. ICC for the 1RM weighted chin-up was between 0.82 and 0.90 whilst the CV was 4.3%, respectively.[20,113] For the 3RM weighted chin-up test, ICC and CV were 0.82 and 4.3%, respectively. The discriminant validity was assessed in 13 (12%) studies and included discriminated between playing standards, playing ages, selected and non-selected players and playing positions (Appendix 8). The 3RM bench press was non-significantly, negatively correlated with total distance (r = -0.87), low-speed distance (r = -0.86), high-speed distance (r = -0.88) and repeated high-intensity efforts (r = -0.66) during a rugby league match.[106] In contrast, non-significant positive correlations were observed for chin-ups and total distance (r = 0.77), low-speed distance (r = 0.76), high-speed distance (r = 0.78) and repeated high-intensity efforts (r = 0.65).[92] There was a degree of shared covariance between characteristics with the 1RM bench press related to bench row (r = 0.89), power clean (r = 0.51), full squat (r = 0.58), 1RM pull-up (r = 0.52-0.93), bench throw power (r = 0.84), bench throw power with 20 kg load (r = 0.71) and repetitions to fatigue during the bench press with 60 kg load (r = 0.83).[12,15,20]

Comparisons between groups indicated that those players at higher playing standard, that were older, and that were selected out-performed the comparator group, with differences between playing positions highly variable. These results suggest measures of upper-body strength can discriminate between groups. The sensitivity of upper-body strength measures was explored in 7 studies across the competitive season,[245,253] multiple seasons[246,252] and specific training periods.[54,213,232] Across the season, Till et al.[245,253] observed improvements of 6.3 to 10.8 kg for the 1RM prone row and 3.8 to 15.1 kg for the bench press in junior rugby league players. Across multiple seasons, there was a linear increase in 1RM prone row and 1RM bench press from U16 through to U19.[246,252] Specific rugby training lasting between 6 and 8 weeks elicited small improvements in upper-body strength in two studies[213,232] with no change observed by Coutts et al.[54]

3.3.8. Reactive strength

Reactive strength was measured in two studies (1.9%) using a drop jump from ~0.3 m to measure a reactive strength index.[69,188] This represents the predicted jump height that would be achieved with a ground contact time of 1 s[141] and is calculated as the ratio of jump height (in meters) to contact time (in seconds). In addition, McMahon et al.[188] calculated the RSI from a single and repeated CMJ whereby contact times was taken from the initiation of CMJ take-off.[188] Such a measure provides insight into a player's ability to generate a rapid stretch-shortening cycle, albeit achieving a rapid SSC (i.e. < 250 ms) is difficult regardless of instruction to minimise contact time.[188] The reliability of the RSI measures on a 1000 Hz force platform has been reported for a CMJ and drop jump in rugby league players.[188] Results demonstrated an ICC and CV of 0.82 and 5.6% for the CMJ, respectively, and an ICC and CV of 0.86 and 8.2%

for the drop jump, respectively. The authors also noted a degree a covariance between jump heights derived form a CMJ and drop jump, though this association diminished when expressed as a ratio of jump height to contact time.[188] Such observations suggest these the two methods do not assess the same RSI properties. RSI does, however, appear to be correlated with change of direction ability,[69] suggesting that a player's ability to perform a rapid eccentric (braking) followed by a rapid concentric contraction (propulsion) is associated with 505 test performance. The concurrent validity of RSI with other physical characteristics or key performance indicators during match-play warrants further investigation alongside a clearer understanding of differences between playing positions and standards. Furthermore, an understanding of the sensitivity of this property to change over a specific training period or intervention and in rugby league players is warranted.

3.3.9. Whole-body strength

Six studies (5.8%) included a measurement of whole-body strength in the form of an isometric mid-thigh pull using a force platform or a portable dynamometer and isometric squat. The aim of each study varied though can broadly be categorised into procedural considerations as well as those assessing the concurrent and discriminant validity. No studies assessed the sensitivity of measures of whole-body power. Five studies measured force using a force platform, whilst the study by Atkins[6] used a portable spring-loaded dynamometer with kilograms of force reported.

The procedures of the isometric mid-thigh pull appear fairly well standardised with participants standing on the force platform or dynamometer, feet shoulder width apart, and the bar height placed at the mid-thigh reflecting the second pull of a power clean[76,78,267] or placed 10 cm above the patella.[6] There were, however, some differences in the procedures that require consideration in future research. Firstly, the knee angle was not standardised for three of the studies[77,79] whereas Atkins[6] standardised this as 135° knee flexion and West et al.[267] used between 120° and 130°. Secondly, the instructions given to participants ranged from “pull as hard and fast as possible”,[79,267] “extend legs with maximal effort”[6] and “pull”.[76] Furthermore, there are inconsistencies with regard to the inclusion or exclusion of a countdown before the pull and encouragement. It is likely that both the terms “fast” and “hard” and the inclusion of a countdown and encouragement are important when trying to achieve maximal muscle activation and peak rate of force development and should be standardised when assessing isometric mid-thigh pull strength. Finally, it is important to standardise the use of hand strapping during the isometric mid-thigh pull. West et al.[267] and Dos Santos et al.[78] both included hand strapping whilst others did not.[6,76]

The within-session reliability of the isometric mid-thigh pull has been reported in studies using rugby league players with an ICC and CV for peak force ranging from 0.91 to 0.97 and 3.2% to 9.2%, respectively, with the lowest variance for peak force, peak force at 100, 150 and 200 ms, and rate of force development at 100, 150 and 200 ms observed when using a onset threshold of 2.5% body mass[76] with no influence of sampling frequency.[78] The between-session reliability and SWC in performance for isometric mid-thigh pull in rugby league players is currently unknown, research in soccer has revealed an ICC and CV of 0.86 to 0.96 and 3.8 to 7.9%, respectively.[77] The within- and between-session reliability for the isometric squat and isometric mid-thigh pull on the dynamometer are unknown.

The discriminant validity of the isometric mid-thigh pull has been explored in two studies with results indicating minimal differences between professional and semi-professional players using dynamometer (230 ± 40 *cf*. 222 ± 37 kgf). These did, however, significantly outperform the academy players (188 ± 30 kgf).[6] Similarly, Ireton et al.[160] reported that senior players out-performed both academy and youth rugby league players during an isometric mid-thigh pull on the force plate (3851 ± 503 *cf.* 3272 ± 329 *cf.* 2157 ± 218 N). Comfort et al.[51] reported that forwards demonstrated greater isometric squat strength (3121 ± 611 *cf.* 2927 ± 607 N) compared to backs albeit, this was not significant. Using the force platform, West et al.[267] explored the relationship between peak force during the isometric mid-thigh pull and reported positive correlations with 10 m sprint times (r = -0.37) and CMJ height (r = 0.45). Whether there is any correlation between isometric mid-thigh pull or squat strength with match characteristics remains unknown. Furthermore, whilst the force plate is regarded as the criterion method, the technical expertise and costs associated with this method, supports the use of a dynamometer such as that used by Atkins et al.[6] However, before such apparatus can be used, the reliability and validity of this measure requires further investigation.

3.8.10. Strength endurance

Strength endurance was evaluated in 8 studies (7.8%) and typically included repetitions to failure during a bench press, chin-ups, tricep drips, sit-ups, press ups and plyometric press ups (Table 2). The bench press repetitions to failure included no load, absolute loads of 60[12,18,113] and 102.5 kg,[18] and a relative load of 60% 1RM.[18] Chin-ups and tricep dips were used with the total number of repetitions completed as the dependent variable. The plyometric push up involved athletes getting into a push-up position with their hands placed on the floor shoulder width apart. From here, players lowered and then forcefully pushed up and landed with their hands on a 5 kg medicine ball. This was then repeated for 30 s with the aim of completing as many repetitions as possible. Similarly, the sit-up, chin-up and press-up tests of muscle endurance were conducted over a 60 s period with the aim of performing as many repetitions as possible. The sit-up test required players to sit on the floor, feet flat with a knee angle of approximately 90° and arms placed across the chest. On the "go" signal, players completed as many repetitions as possible, which required elbows to touch the front thigh and the lower back to be in contact with the ground.[121] The press-up required participants to have their hands placed underneath the shoulders before lowering until the elbows were flexed to 90°, keeping their legs and back straight throughout the repetition.[257] Finally, the chin-up required participants to place their hands on the bar with an overhand grip and arms fully extended. From here, participants pulled themselves up until their chin was level with the bar.[257]

The measurement properties were reported in 5 studies with the ICC for the 60 kg bench press between 0.80-0.94 and CV of 7.3%.[12,112] No reliability information was reported for 102.5 kg or 60% 1RM. For the unloaded bench press, the ICC and TE were 0.80 and 7.3%, respectively. Repetitions to failure of the chin-up possessed an ICC and CV of 0.99 and 2.6%, respectively. No information was available for tricep dips, 30 s plyometric push up or 60 s sit-up test. ICC and CV for the 60 s chin-up and press-up tests were 0.98 and 6.4%, and 0.94 and 7.3%, respectively. The concurrent validity of tests of muscle endurance against match-play is yet to be explored, though triceps and chin ups to failure were non-significantly associated with tackling ability. The discriminant validity was explored in three studies, with a significantly lower number of repetitions for intra-city (25.3 ± 4.4) compared to intra-state (32.2 ± 4.5) and national (36.6 ± 8.5) players. Similarly, differences in number of repetitions were observed between national and state players for the bench press at 60 kg (36.1 ± 7.2 *cf.* 28.0 ± 5.6) and 102.5 kg (12.5 ± 4.3 *cf.* 5.9 ± 3.9) but not 60% 1RM (20.5 ± 3.1 *cf.* 20.7 ± 3.2). The sensitivity has only been explored in one study, which used repetitions to failure during the chin-up. Results revealed that this was sensitive to a 6-week period of overload training (15.6 ± 19. *cf.* 13.4 ± 2.1) and a 7-day taper (16.0 ± 1.7), both of which exceeded the minimally clinically important differences.[54]

3.8.11. Agility (reactive)

Reactive agility, referring to a player's ability to perform a rapid change of direction in response to a sport-specific stimulus,[223] has received limited attention in rugby league with only two studies included.[110,124] Both studies used the same reactive agility test, which required players to react to the movement of the investigator who triggered the start of the test. The players moved forward, then to the left or right in response to the movement of the investigator and then stopped the test by triggering the timing beam.[224] The reactive agility test and its individual components, including movement time, decision time and response accuracy, have been reported to discriminate between elite professional and amateur players,[67] whilst only movement time was reported to discriminate between first and second grade (professional) players.[124] Gabbett et al.[124] reported that movement time from the reactive agility test was significantly related to 10 and 20 m sprint times and change of direction speed. The sensitivity of the reactive agility tests to training (training period or intervention) is currently unknown in rugby league players and warrants investigation with consideration for the reliability for movement time (ICC = 0.92; CV = 2.1%), decision time (ICC = 0.95; CV = 8.7%) and response accuracy (ICC = 0.93; CV = 3.9%).[124]

3.8.12. Change of direction (pre-planned)

Change of direction ability refers to the ability of a player to execute a pre-planned series of movements in as little time as possible[223] and has been used in 31% of studies. Although often termed agility, there are several change of direction tests currently used with the majority (82%) including tests such as the L-run, Illinois and 505 tests. A further 4 tests were used to assess the change of direction ability of players including a zig-zag test with 4 changes of direction of non-specific angles or detailed movement patterns,[202] a modified 505 test that placed emphasis on a short acceleration,[124] an unnamed test that required players to perform a 5 m sprint, 135° turn from their left foot, 2.5 m sprint, a 45° change of direction from their right foot followed by a 5 m sprint,[51] and finally a change of direction test whereby players covered 40 m in total including two 45° and one 135° changes of direction.[13]

Across all tests used to evaluate the change of direction ability of rugby league players, there were many inconsistencies in the reporting. Whilst the movement patterns participants completed were fairly well described, many studies did not report the number of trials participants completed, the inter-effect recovery, reliability properties; surface, or whether the mean or peak values were used for analysis. Such findings highlight the need to provide a standardised set of reporting criteria in an attempt to make comparison across the literature.

The reliability of the 505 test was reported in 36% of studies, with an ICC between 0.82 to 0.97 and CV between 1.3 and 3.5%.[46,109,117,119,120,217,249] Only one study reported the typical error for the 505 test at 0.032 s.[217] The ICC and CV for the L-run ranged between 0.84 and 0.90, and 1.9 and 2.8%, respectively. Only two studies use the Illinois agility test, which is reported to possess an ICC of 0.86 and CV of 2.0%. For the lesser known tests, the reliability properties were not reported in most studies.[13,51,202] The ability of these tests to discriminate between playing standards, age group, maturation status and playing position have been explored and is presented in Figure 9. Results indicated that change of direction time is likely to differentiate between playing ages, selected/non-selected, playing position and performance standards, though there is a high degree of variability. The concurrent validity against match-play has not been explored, though Gabbett[119,120] revealed a small correlation between 505 change of direction time and tackling ability (r = 0.14 to -0.20). Results determining the change in pre-planned change of direction ability revealed trivial-to-small changes across the season. In all three cases, times improved from off-season to the end of preseason, where thereafter times then increased until the end of season in two studies[89,97] and continued to improve to mid-season in one study[118] before increasing at the end of season. Those evaluating a specific training period revealed that after 9 weeks of conditioning- or skill-based training, small, non-significant improvements were observed in L-Run times (skill = 5.73 ± 0.04 s *cf.* 5.70 ± 0.03 s; conditioning = 5.78 ± 0.03 s *cf.* 5.74 ± 0.07 s).[123] In contrast, 14 weeks of field-based conditioning appeared effective for significantly improving L-run times in junior (5.81 *cf.* 4.78 s) and senior (5.96 *cf.* 4.99 s) rugby league players.[11]

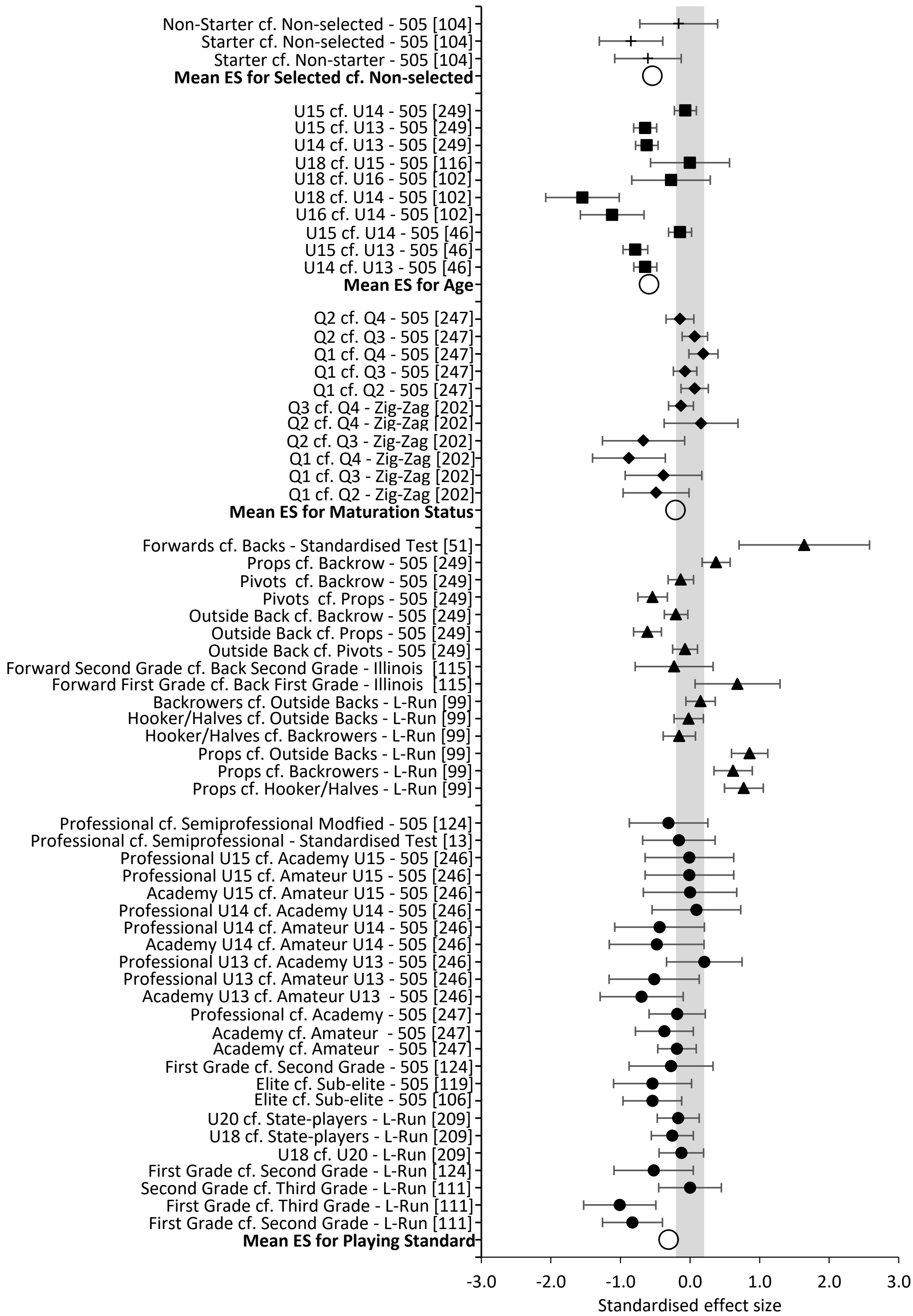

Figure 9. Mean effect size (± 90% CIs) between starters/nonstarters (line), age categories (square), maturation status (diamonds), positions (triangle) and playing standards (circles) for change of direction times. Q = quartile. Open circle represents the mean effect size for each factor.

3.8.13. Repeated high-intensity effort

Rugby league players must frequently engage in tackling, wrestling and high-impact collisions whilst maintaining high-intensity running,[10] resulting in the emergence of tests to assess repeated high-intensity effort ability (RHIE). One test required players to complete 12 x 20 m sprints and tackles with each sprint commencing every 20 s and a single tackle performed immediately after the sprint, which consisted of a 2 m acceleration and a 3 s grapple.[164] Once complete, players have the remainder of the 20 s to recover before performing the next bout. Another test used a position-specific RHIE test whereby players completed three efforts[10] comprising three 20 m sprints through timing gates each followed by a short active recovery. Once all three sprints were complete, players were given 60 s recovery and then asked to complete 2 (backs) or 5 (forward) tackles against a tackle bag, each preceded by a 10 m acceleration and 2 m drive, performed on a 20 s cycle.[10]

The ICC, TE and CV for the RHIE test used by Johnston and Gabbett[164] was reported at 0.82, 1.00 s and 2.3% for total distance and 0.91, 1.04 s and 6.7% for percentage performance decrement, respectively. Austin et al.[10] reported the reliability for the backs test total time (ICC = 0.82; TE = 0.001-0.032 s; CV = 0.1-3.2%) and performance decrement (ICC = 0.78; TE = 0.04-0.50 s; CV = 4.2-49.5%). The reliability of the rugby league forwards RHIE test was also reported for total time (ICC = 0.97; TE = 0.001-0.049 s; CV = 0.1-4.9%) and performance decrement (ICC = 0.86; TE = 0.01-0.48 s; CV = 1.4-48.2%). The association between RHIE measured using one of the performance tests highlighted in the review on key performance indicators in rugby league is currently unknown and warrants further research. The relationship between RHIE ability and Yo-Yo IR1 has been reported as moderate ($r = 0.43$, $P > 0.05$) and weak ($r = 0.29$, $P > 0.05$) in backs and forwards, respectively.[10] Such relationships have been observed elsewhere[92] and is likely explained by the lack of a sport-specific action during a running-based shuttle test. Significant relationships were observed between improvement in RHIE time between the second, sixth and tenth weeks of preseason and 20 m sprint times in forwards but not backs.[10] The sensitivity of the RHIE test was only explored by Austin et al.[10] with no significant change observed over the preseason period in total time for backs and forwards despite overall reductions of 0.54 s and 0.53 s. For performance decrements, a non-significant reduction was observed for backs (0.13 s) and forwards (0.09 s).

3.9.14. Maximal aerobic capacity ($\dot{V}O_{2max}$) and speed

Maximal aerobic capacity ($\dot{V}O_{2max}$) was evaluated in 35 studies with most studies (91%) estimating this using the multi-stage fitness test (MSFT) (Table 2). The MSFT involved players completing as many 20 m shuttles as possible with the time between audio signals reduced (hence an increase in running speed) until volitional exhaustion. The final shuttle and level were then entered into the following regression equation: *14.4 + 3.48*shuttle number*.[39] Whilst volitional exhaustion was noted, there was a lack of detail on the quality control procedures including the number of failed shuttles allowed (if any) and the surface on which the test was completed. The Yo-Yo IR1 was used in a single study to estimate $\dot{V}O_{2max}$ with the participants completing as many 40 m shuttles (2 x 20 m) as possible interspersed with a 10 s recovery period. Players continued until volitional exhaustion or they missed two audio signals. $\dot{V}O_{2max}$ was then estimated using the equation: *Yo-Yo IR1 distance * 0.0084 + 36.4*.[23] The 30-15$_{IFT}$ was used in a single study that required participants to perform 30-s shuttles over a 40 m linear course and interspersed with 15-s periods of passive recovery. $\dot{V}O_{2max}$ was estimated using the following equation: *28.3 –(2.15*gender(1 male, 2 female) – (0.741*age) – (0.0357*body mass) + (0.0586*age) + (1.03*final velocity)*.[32] The same study also assessed $\dot{V}O_{2max}$ using a maximal graded running test on a treadmill. Participants performed a warm-up and then began the test at 8 km·h^{-1}, which increased 1 km·h^{-1} every two minutes until volitional exhaustion. While regarded as the criterion measure, such procedures are difficult to implement with a large number of players due to the time and expense, hence the popularity of the MSFT across the rugby league literature.

Whilst the use of field-based tests are justified when working in team sports such as rugby league, it is important to note that the relationship between direct measures of $\dot{V}O_{2max}$ (indirect calorimetry) and MSFT (r = 0.30 – 0.46)[39,40] Yo-Yo IR1 (r = 0.71 – 0.83)[180,185] and 30-15$_{IFT}$ (r = 0.60 – 0.74)[31,220] indicate a degree of unexplained variance. Furthermore, the results by Krustrup et al.[180] and Buchheit et al.[31] revealed $\dot{V}O_{2max}$ values of between 48 and 49 ml·kg^{-1}·min^{-1} can result in a Yo-Yo IR1 distance of between ~1500 and ~2250 m, and a 30-15$_{IFT}$ final speed of ~17.6 to ~20.2 km·h^{-1}. It is likely that these variances are explained by the differences in measurement procedures, whereby $\dot{V}O_{2max}$ is typically obtained during an incremental treadmill test to exhaustion, whilst field-based tests include accelerations, decelerations, changes of direction, inter-effort recovery and an anaerobic contribution during the latter stages.[39] As such, it is important practitioners are aware of the limitations associated with estimating $\dot{V}O_{2max}$ from field-based measures in rugby league.

Maximal aerobic speed (MAS) was reported in two studies and was measured using a 5-minute run[189] and a 2 km time trial.[220] The 5-minute run was performed around the perimeter of a pitch with cones placed at known distances, whilst the 2 km time trial was performed on an outdoor running track. The aim of the 5-min run was to cover as much distance as possible in the allocated timeframe whereas the aim of the 2 km time trial was to cover the distance in as little time as possible.[189,220] These tests are commonly used in applied practice though are limited in the rugby league literature. It is possible for researchers and practitioners to calculate MAS using the average speed during the test and the total time or distance, which can subsequently be used to prescribe training intensity during field-based conditioning.[189,220]

The reliability of the MSFT was reported in almost all studies with an ICC and TE between 0.90-0.92 and 3.1-4.6%, respectively. The reliability of the Yo-Yo IR1 and $30\text{-}15_{IFT}$ was not reported, though is known to be 4.9% and between 2.3-3.1%, respectively.[38,180] No reliability was reported for either the 5-minute run or 2 km time trial. The concurrent validity of the MSFT, $30\text{-}15_{IFT}$, direct measures of $\dot{V}O_{2max}$ and MAS with match-play are unknown. $\dot{V}O_{2max}$ derived from the MSFT is significantly associated with play-the-ball speed (r = 0.310).[111] The relationships between the Yo-Yo IR1 and measures of load during match-play revealed trivial correlations with total (r = 0.05), low-speed (r = 0.04), and high-speed distance (r = 0.09), though was negatively associated with the number of tackles (r = -0.70) and RHIE (r = -0.23).[92]

The sensitivity of estimated $\dot{V}O_{2max}$ was noted across the season[89,98,118] and specific training periods.[50,117,123] Across the season, a similar pattern was observed with large changes from the off-season (42 – 43.7 $ml \cdot kg^{-1} \cdot min^{-1}$) to pre-season (47.8 – 50.6 $ml \cdot kg^{-1} \cdot min^{-1}$); small changes from pre-season to mid-season (47.6 – 53.5 $ml \cdot kg^{-1} \cdot min^{-1}$); and a small reduction observed at end of season in two studies (49.6 – 52.1 $ml \cdot kg^{-}$

$^{1}\cdot$min^{-1}). Estimated $\dot{V}O_{2max}$ and total distance during the MSFT appear sensitive to change after 7,[54] 9[123] and 10[117] weeks of training. The sensitivity of the MAS tests is currently unknown in rugby league. The ability of maximal aerobic capacity to discriminate between age categories, playing position, performance standards, selected/non-selected and maturation status is presented in Appendix 8. It appears that estimated $\dot{V}O_{2max}$ was, for the most part, higher in older players, those competing at a higher standard and those selected, with differences between playing position and maturation status more variable. The discriminant validity of the 5-minute run or 2 km is currently unknown and given its use in the applied field, warrants investigation.

3.9.15. Prolonged high-intensity intermittent running

Three performance tests were identified that measured rugby league players' ability to perform prolonged high-intensity intermittent running. Of these, the most commonly used test was the Yo-Yo IR1,[23,180] which assesses a player's capacity to perform intermittent exercise and inter-effort recovery.[23] The Yo-Yo IR1 has been used extensively across a number of team sports including rugby league where it appears to significantly differentiate between selected and non-selected players (1506 ± 338 *cf.* 1080 ± 243 m; $P < 0.05$)[92] and U18 and U19 players (1408 ± 281 *cf.* 1548 ± 379 m; $P < 0.05$).[252] In contrast, no significant differences were observed between professional and semi-professional players (1656 ± 403 *cf.* 1564 ± 415 m; $P > 0.05$);[5] those progressing to professional compared academy status at U17 (1553 ± 287 *cf.* 1436 ± 336 m), U18 (1535 ± 322 *cf.* 1464 ± 354 m) and U19 (1443 ± 259 *cf.* 1475 ± 443 m) ($P > 0.05$);[246] and between U18, U20 and state league players (909 ± 313 *cf.* 894 ± 368 *cf.* 960 ± 339 m).[209]

The Yo-Yo IR1 test is reported to possess concurrent validity albeit, much of this work has been established in soccer.[180] In rugby league, Gabbett and Seibold[92] reported non-significant trivial correlations with total (r = 0.05), low-speed (r = 0.04) and high-speed (r = 0.09) distance in a match, though the high match-to-match variability and lack of sport-specific actions might explain these findings.[92] During an intensified competition, junior players with a higher Yo-Yo IR1 distance covered greater high- and very high-speed distance during a match as well as an improved recovery of neuromuscular function after 24-48 hours.[169] Although limited to soccer, TE for the Yo-Yo IR1 has been reported to range from 4.1% to 17.3%.[23,73,74,86,180] Using the TE reported by Deprez et al.[74] for the U19 age group (~74 m) and smallest worthwhile change in a similar sample (~66.9 m),[73] the Yo-Yo IR1 appears sensitive to changes of approximately 140 m (TE + SWC); a minimum change that has been observed after 10 weeks of pre-season training in forwards and backs,[10] and after a full competitive season in academy players with 1 or 2 years' experience.[245,253]

A second test that has gained interest in rugby league is the $30\text{-}15_{IFT}$,[219-221] which is similar to the Yo-Yo IR1 in that it can be used to evaluate the cardiorespiratory fitness of players as well as their ability to change direction, inter-effort recovery and their anaerobic contribution during the final stages of the test.[31] However, unlike the Yo-Yo IR1, the $30\text{-}15_{IFT}$ provides practitioners with a maximal running speed (V_{IFT}) that can be used to aid training prescription.[31] To date, three studies have used the $30\text{-}15_{IFT}$ with rugby league players. In brief, the test required players to perform repeated 30 s shuttle running starting at 0.5 $km \cdot h^{-1}$ and increasing 0.5 $km \cdot h^{-1}$ every 45 s with shuttles interspersed with 15 s passive recovery. It is also noteworthy that the required distance was adjusted in accordance with the number of changes of direction given the greater metabolic load this imposes.[4,31,208]

The 30-15$_{IFT}$ is reported to be associated with several other characteristics (i.e. MAS, skinfold thickness, 10 m sprint time and $\dot{V}O_{2max}$),[127] however the concurrent validity and discriminant validity of this test are currently unknown. The test is reported to be reliable using rugby league players with a TE ranging from 0.25 to 0.37 $km \cdot h^{-1}$ and CF of 1.8 to 2.1%.[219] Such results are important when interpreting the sensitivity of the 30-15$_{IFT}$ as both the TE and SWC requires consideration before the certainty of the change being 'true' can be ascertained.[144] For example, Seitz et al.[221] reported an increase in V_{IFT} after 8 weeks of small-sided games training (19.35 ± 1.00 *cf.* 19.60 ± 0.77 $km \cdot h^{-1}$; $P = 0.05$), however it is likely that the improvement observed for some players did not exceed the combined TE and SWC reported by Scott et al.[219] of 0.36 $km \cdot h^{-1}$ and 0.21 $km \cdot h^{-1}$, respectively. Further research is required to explore the magnitude of change typically observed after a range of training interventions in rugby league.

Three studies (2.8%) used a repeated 12 s sprint-shuttle test to measure prolonged high-intensity intermittent running that required players to perform 8 x 12 s maximal efforts shuttles (sprint forward 20 m, turn 180°, sprint 10 m, turn 180° and sprint 20 m) on a 48 s cycle. The outcome variables from this test are total distance and the percentage decrement in distance covered as the test progresses. The concurrent validity of the 8 x 12 s test has been explored and is positively associated with the number of minutes played[121] and risk of non-contact injuries.[113] The discriminant validity has only been explored in one study with no significant difference observed between selected and non-selected players, and starters and non-starters amongst a sample of professional rugby league players.[104] Such findings are explained by the homogeneity of the sample used and, as such, further research is needed to explore if this test can discriminate between playing standards (i.e. academy vs. senior) and positional groups (i.e. forwards vs. backs). Whilst the sensitivity of the test is unknown, the reliability has been reported as 'good' with an ICC of 0.91 and CV of 4.3%. The SWC for this test is currently unknown.

Of the 15 studies that have reported measuring high-intensity prolonged high-intensity intermittent running, they have either used the Yo-Yo IR1 (60%), $30\text{-}15_{IFT}$ (20%) or 12 s sprint-shuttle test (20%). However, all these tests are predominantly running-based and include limited sport-specific actions associated with rugby league. In the development of the rugby league match simulation protocol, authors Sykes et al.[236] Waldron et al.[261] Norris et al.[205] incorporated rugby league-specific actions to better reflect the load experienced during match-play through increasing the physiological strain imposed.[204] Whilst the concurrent validity of the $30\text{-}15_{IFT}$ and 12 s sprint-shuttle test are unknown, the lack of association between the Yo-Yo IR1 and key match and actions raises questions on the applicability of a running-based test in rugby league. With this in mind, future research might consider incorporating sport-specific actions within a test of prolonged high-intensity intermittent running as well as establishing key measurement properties that include reliability, validity and sensitivity.

3.9.17. Qualitative assessment of movement proficiency

Five (5.4%) studies in this review evaluated the movement proficiency of rugby league players and included one or more components (Table 2). With the exception of

Georgeson et al.[127] who only measured balance, determined as the time stood on a single foot with their forearms across the chest at shoulder height, eyes closed, and foot raised the height of the opposite ankle, the remaining studies included multiple tests as part of a battery. Two studies used the Athletic Ability Assessment (AAA), one study used the Qualitative Movement Assessment (QMA) and another used the Functional Movement Screen™ (FMS™) (Table 2). Each of these involved a number of movements that are documented in the corresponding studies. The AAA and FMS™ is graded on a 1-3 scale, whilst the QMA is assessed on a 5-point scale. In two studies, the assessment was recorded using a video camera with the results determined retrospectively with an intra-rater reliability of between 0.62 and 0.81 for the AAA. In the study using the QMA, the movement was scored by two researchers with an inter-rater reliability of > 0.80. The discriminant validity of the QMA indicated that late maturers scored significantly lower than average maturers but not early maturers.[202] Ireton et al.[160] reported higher right-limb lunge (7.5 ± 1.1 and 7.0 ± 0.8 *cf.* 5.7 ± 1.0), press-ups (7.2 ± 1.5 and 6.4 ± 1.6 *cf.* 5.4 ± 1.4), pull-ups (6.8 ± 1.9 and 6.3 ± 2.0 *cf.* 5.0 ± 1.5) and total AAA score (47.2 ± 6.1 and 44.4 ± 4.8 *cf.* 40.8 ± 6.2) in senior and academy players compared to youth. There was no difference in AAA between academy (U19) and senior players for any measure. Pearce et al.[209] observed higher double lunge on the left, single leg Romanian deadlift and push-up scores in state-league players compared to U18 and U20 players. With regard to sensitivity to change, Waldron et al.[260] observed no meaningful change in total FMS™ score or individual test components (pre-season = median 14; mid-season, median = 14 and late season = median 14).

Table 3. Summary of field-based options and alternatives (i.e. laboratory) for practitioners and researchers selecting tests of anthropometric and physical characteristics.

		Field-based testing options	**Alternative options**
Anthropometric	Stature	Portable stadiometer	Wall-mounted stadiometer
	Body mass	Portable scales	Beam scales
	Sitting height	Portable stadiometer	Wall-mounted stadiometer and stool
	Fat mass	7-site skinfolds	Dual-energy x-ray absorptiometry
	Fat free mass	7-site skinfolds	*Not reported in the rugby league literature*
	Lean mass index	7-site skinfolds	*Not reported in the rugby league literature*
	Lean mass	*Not reported in the rugby league literature*	Dual-energy x-ray absorptiometry
	Bone mineral content	*Not reported in the rugby league literature*	Dual-energy x-ray absorptiometry
Physical characteristics	Linear sprint speed	Timing gates (2-, 5-, 10-, 15-, 20- and 30 m)	Non-motorised treadmill
	Change of direction	L-Run, 505, Illinois or one of three standardised tests	*Not reported in the rugby league literature*
	Reactive agility	Standardised reactive agility test	*Not reported in the rugby league literature*
	Lower-body strength	*Not reported in the rugby league literature*	Back squat, isometric squat, isokinetic dynamometry
	Reactive strength index	Jump mat system or portable force plate	Force platform
	Upper-body strength	*Not reported in the rugby league literature*	Bench press, weighted chin-up, prone row
	Whole-body strength	Isometric mid-thigh pull using portable dynamometer	Isometric mid-thigh pull using force plate
	Lower-body power	Countermovement jump, vertical jump, unilateral hop	Loaded squat jumps on force plate or using inertial sensor
	Upper-body power	Seated medicine ball throw, plyometric push-up	Bench press, bench throw
	Whole-body power	*Not reported in the rugby league literature*	Power, hang and mid-thigh clean
	Muscle endurance	Triceps dips, press ups, chin ups, sits-ups	Loaded bench press
	Repeated sprint ability	12 x 20, 8 x 20, 6 x 30, 10 x 40 repeated sprint tests	*Not reported in the rugby league literature*
	Repeated effort ability	12 x 20 repeated effort test, 3 x 20 forwards and backs	*Not reported in the rugby league literature*
	Aerobic capacity	Multi-stage fitness test, 30-15 Intermittent fitness test, Yo-Yo Intermittent Recovery Test Level 1	Graded aerobic test using indirect calorimetry
	Aerobic speed	2 km time trial, 5 minutes run on track/field	2 km time trial, 5 minutes run on treadmill
	Prolonged high-intensity intermittent test	30-15 Intermittent fitness test, Yo-Yo Intermittent Recovery Test Level 1, 12s x sprint test	*Not reported in the rugby league literature*
	Qualitative assessment of movement proficiency	Double lunge, single leg Romanian deadlift, press-ups, pull-ups, balance, sprint test, change of direction test, countermove movement jump, squat, superman, medicine ball throw, hop-stick-grip, shoulder mobility, active straight leg raise, rotary stability	*Not reported in the rugby league literature*

2.4. Discussion

The primary aim of this chapter was to conduct a systematic review of the tests used to assess the anthropometric and physical characteristics of rugby league players with a view of optimising a proposed battery of tests provided by the RFL. In doing this, a secondary aim was to document the measurement properties of tests used across the literature including the reliability, validity and sensitivity. The literature search yielded a large number of studies that tested predominantly (91.4%) UK- and Australian-based rugby league players. Such an observation reflects the popularity of rugby league in these countries as well as the two highest profile leagues, the European Super League and the National Rugby League. Sixty-three percent of studies included players that were considered senior whilst 48.9% of studies included junior (youth and academy), which likely reflects the high degree of collaboration between researchers and professional clubs that enables access to elite athletes. The assessment of anthropometric and physical characteristics is common practice in team sports such as rugby league and serves a number of important functions within the applied setting, including training prescription, return-to-play assessments, player monitoring, aiding selection and evaluating talent development and training practices. This systematic review highlighted that 38 anthropometric and 17 physical characteristics were evaluated using a wide range of tests (Table 3).

One of the most important findings that emerged from this systematic review was the large number of tests available to practitioners to evaluate the anthropometric and physical characteristics of rugby league players. The review highlighted a large number of anthropometric measures that are used in rugby league with stature, body mass and skinfold thickness being included in a large number of studies that demonstrate these characterisitics possessed discriminant validity and are reliable measures. As such, both stature and body mass should be included in a standardised battery of tests with skinfold measures included at specific phases or if time permits. Other more specific measures (i.e. femur length) might be included in specific circumstances at an individual level and completed by a trained anthropometrist. For assessing the physical characteristics, there were a large number of tests available with linear sprint, change of direction, upper- and lower-body muscle strength and power, and aerobic capacity or prolonged high-intensity intermittent running being the most common characteristics evaluated. The proposed battery from the RFL (called SPARQ) included a single 20 m sprint, a countermovement jump, a zig-zag shuttle, medicine ball throw and a rugby-specific Yo-Yo IR1 test.

Based on the results of the systematic review, some changes were made to the original battery contributing to the rationale behind renaming the battery to RLAP. One such change was based on few studies including a single (*n* = 3) or greater than 3 measures (*n* = 12) of sprint times, likely reflecting the need to understand players' ability to cover distances frequently performed during a match (i.e. 10-20 m)[100] as well as the cost associated with timing gate systems. Therefore, a 10 m split time was included in the RLAP battery to provide insight into players' ability to cover a shorter sprint distance that is common in the game.[100] Two tests included in the RFL's battery were the standing medicine ball throw and zig-zag agility test which has received minimal consideration previously. The medicine ball throw included in the literature was completed in a seated position or with the ball being thrown overhead that emphasises upper-body. No field-based method for whole-body power was reported. Furthermore, the change of direction test included in the RFL's battery included multiple changes of direction across range of angles allowing emphasis to be placed on cutting ability unlike those commonly used where angles were 90-180°. As such, both tests remained in the battery with the aim of the programme of research to determine their usefulness and measurement properties. Lower-body power was commonly assessed using the same tests proposed by the RFL. Tests of aerobic capacity or prolonged high-intensity intermittent running included in the previous research largely used the MSFT, Yo-Yo IR1, $30\text{-}15_{IFT}$ or 12 s sprint test, with all tests involving linear running and a change of direction. In attempt to improve the ecological validity of these running-based tests, the one included in the RLAP battery required participants to start each 40 m shuttle in a prone position. Whilst its inclusion in the battery is unsubstantiated, anecdotal evidence from coaches and players led the researcher to retain this test and place an emphasis of the research on understanding it in greater detail before providing final recommendation for its continued use. One characteristic not included in the initial battery was strength, with only one study using a method suitable for a field-based battery. Whilst a mid-thigh pull using dynamometer has been used and could have been included, it was omitted due to several reasons; 1) the researcher did not have access to this at the start of the programme of research, 2) the reliability, validity and sensitivity were largely unknown, 3) almost all clubs did not possess one and therefore would require investment after completion of this project and 4) it was unknown if this method was suitable for all ages given the lack of habituation to maximal strength work at junior and amateur standards of the game.

The wide array of performance tests available to practitioners reinforces the importance placed on the anthropometric and physical characteristics in rugby league and is likely influenced by the individual club-approach taken across the rugby league literature. This finding reinforces the concerns previously raised regarding the inability to compare findings across studies, clubs and countries as well as the absence of normative data in rugby league.[255] Further, few studies have explored the anthropometric or physical characteristics of rugby league using multiple clubs, as reflected by the relatively small sample sizes (Table 1). In all, 6 (5.7%) studies included multiple clubs, whilst a further 8 (7.4%) used a large sample of players over multiple years (i.e. National Performance Pathway). To overcome some of these issues, Till et al.[255] suggested undertaking large-scale studies using a standard battery of tests in order to determine league-wide trends in data and provide 'true' normative data for practitioners in the applied setting. However, to achieve this, it is essential the RLAP was accessible at all standards (i.e. amateur, semi-professional and professional), includes tests suitable for numerous age groups (i.e. youth, academy and senior), is efficient, and can be continued by the club's practitioners. From a scientific perspective, it is also essential that the measurement properties are known for each test along with an understanding of the physiological construct being evaluated and contextual factors that might influence these. The measurement properties should include 1) test-retest reliability, 2) discriminant validity, 3) concurrent validity and 4) sensitivity to training. Therefore, with the individual tests included in the battery confirmed, it is essential to determine their measurement properties, the physiological construct (where unknown) evaluated and understand the contextual factors that influence these characteristics.

This review also confirms the poor quality of procedural detail reported by many studies. Using the assessment of linear speed as an example, studies did not report sufficient details to enable accurate interpretation of the results. Insufficient details were provided on the starting position of the player, gate placement, proximity to the initial gate, the recovery between efforts, number of sprint efforts, and the use of peak or mean split times. Similar observations are true for almost all tests reported in this review, indicating that a clear and detailed procedural overview ought to be provided in this programme of research for others to replicate without any need for interpretation that could lead to bias. There was a high degree of inconsistency observed in testing procedures between studies, highlighting the need for practitioners to consider the existing literature-base when selecting a test and conducting these assessments. Using the isometric mid-thigh pull as an example, the instructions given to the players varied across the five studies with “hard and fast”, “extend legs with maximal effort” and “pull” used and thus, making it difficult to determine if differences across the studies are population-based or influenced by the instructions given.[44] Based on these observations, there is a need for practitioners and researchers in rugby league to standardise the assessment of anthropometric and physical characteristics as much as possible, which was a key focus of this research.

The reliability associated with the tests of anthropometric and physical characteristics was reported inconsistently, with a large number of studies reporting no information on retest reliability. A thorough understanding of the reliability or ‘noise’ associated with a test is fundamental in the applied sport setting with better reliability reflecting a better precision in determining a specific characteristic and/or tracking over time.[146] The lack of information on the retest reliability is limitation of the currently literature and might result in incorrect interpretation of the data such as a false positive result (i.e. a change in magnitude that is similar to the ‘noise’ of a test). It is therefore essential that researchers and applied practitioners have a thorough understanding of the reliability of their tests, with statistics that provided insight into the within-subject variation being most applicable.[147] A measure of the within-subject variation included in few studies in this review was typical error (TE) or when expressed as a percentage of the mean, coefficient of variation (CV). Unlike the 95% limits of agreement (LoA), which is influenced by the sample size, requires consideration for the degrees of freedom when comparing across studies, and is suggested as too stringent in applied sports sciences,[147] TE and CV provides a simple measure of the observed variation in repeated measures, with the latter being useful to compare across studies. Another reliability statistic that was frequently reported in the literature was the ICC, which provides a representation of how closely two related measures relate to each other, though has use when accounting for the change in an outcome variable.[7,147] In all, a large number of studies in this review have not included the reliability of the performance test outcome(s) and future research developing tests or using a battery should seek to understand and present the reliability statistics to aid researchers and practitioners in the interpretation of results.

In addition to the reliability statistics, it is important for researchers and practitioners to have some understanding of what is considered a worthwhile or meaningful change in a performance outcome. The results of this systematic review highlight that the SWC, calculated as 0.2 multiplied by the between-trial standard deviation, was included in very few studies. As such, the worthwhile change for almost all tests included across rugby league practice is largely unknown and should be a focus of future reliability studies. It is, however, important to consider how this worthwhile change is determined. Often, the use of 0.2, which is considered a small effect size,[235] is used in applied sports, though several other approaches could also be used. These include a practically meaningful change in a sporting context (i.e. 0.03-0.06 to be 50-60 cm ahead of an opponent over 20 m in soccer),[135] an analytical goal based on a previous observed change in performance[7] or a change the coach deems to be worthwhile. In this review, few studies provided an interpretation of the change against any of these criteria, making it difficult to determine a practically meaningful change in performance when using an array of tests available. Furthermore, only one study included in this review took into account both the reliability (i.e. TE) and the worthwhile change (i.e. SWC).[62] Using a magnitude-based inferences approach, exceeding both the TE and SWC provides practitioners with 75% confidence an observed changes is 'true' and worthwhile, providing a single value that can be used as an analytical goal.[135] Finally, despite some studies reporting the reliability of the test, it is particularly noteworthy that none of the studies included in this review achieved the recommendations outlined by Hopkins.[147] Indeed, no studies included a sample of ≥ 50 participants across at least three repeated trials which might impact on the precision of the estimate of error associated with a test.

There was a dearth of literature that explored the concurrent validity of tests of anthropometric and physical characteristics with match-play. There were, however, several studies that assessed the concurrent validity of characteristics with tackling ability and skill performance during conditioning games as well as the covariance between anthropometric, body composition and physical characteristics. The lack of understanding around the concurrent validity of tests for linear speed, repeated sprint ability, upper- and whole-body strength and power, reactive strength index, reactive agility, change of direction ability, RHIE, prolonged high-intensity intermittent running and aerobic-based tests against match-play is a concern. This does, however, present an area for future research, whereby focus should be placed on those tests deemed most important in rugby league and that possess appropriate reliability, discriminant validity and sensitivity. For example, it is generally accepted that prolonged high-intensity intermittent running is a fundamental physical characteristic in rugby league,[168,169,219,220] particularly when considering recent rule changes restricting the number of interchange players available and its moderating potential for injury risk.[183] As such, research investigating the association between a novel measure of prolonged high-intensity intermittent running with performance measures of rugby league whilst controlling for the high match-to-match variability, might be useful for practitioners in rugby league.[177] The covariance between characteristics is an important consideration for strength and conditioning coaches in rugby league, whereby placing focus on developing a specific characteristic could positively or negatively influence other characteristics. Therefore, understanding the interaction between tests included in a RLAP battery should be determined which can support the interpretion the result of the battery and inform player development.

Discriminant validity was explored in 57 studies with differences between performance standards, positional groups, age categories, maturation and development status, starters/selected and non-starters/non-selected and groupings based on tackling ability, intermittent running ability or strength. The overall results suggest that of those studies that explored between-groups differences, the tests largely discriminated between the playing groups. Selected players typically out-performed non-selected players for almost all measures whilst the same was true for playing age, with older athletes outperforming their younger counterparts. Players competing at a higher playing standard out-performed those at a lower standard, with this difference larger between professional and semi-professional compared to elite junior players. The discriminant validity of some tests reported in this review remain unknown as do the differences between all players groupings, which might serve as an area for future research. Understanding to what extent the RLAP battery discriminated between playing standards is essential for practitioners in order to make informed decisions on talent development and the training needs of players.

The sensitivity of the tests to changes in physical characteristics across a pre-season period, across a competitive season or across multiple seasons was explored in 27 studies. Fewer studies explored the change over a specific training intervention and likely reflects the difficulties in conducting training interventions within the applied setting albeit, future research might seek to overcome these issues and explore the sensitivity of their battery of tests. Furthermore, the longitudinal changes over multiple seasons has received less attention than changes observed over a single season or specific training period along with any consideration for the factors that might influence these changes. A key focus of this research was therefore to determine the changes in anthropometric and physical characteristics with consideration for contextual factors as well as the sensitivity of the RLAP battery. Such information is important for researchers and practitioners using this battery to have confidence it can detect a meaningful change in performance.

2.5. Conclusion

This review identified a wide array of variables and tests used to assess the anthropometric and physical characteristics of rugby league players. Almost all physical characteristics can be tested using multiple field-based or alternative (i.e.

laboratory) methods. Stature and body mass were the most common anthropometric characteristics measured and CMJ appeared appropriate for assessing lower-body power, justifying their inclusion in the RLAP battery. A single measure of 20 m sprint appeared insufficient based on the available literature and knowledge of the sprinting demands of the game,[100] and therefore an additional split time was included in the assessment of linear speed. Two of the tests included in the original battery were not reported in the available literature questioning their inclusion. However, that no alternative field-based measure of whole-body power was available and that most change of direction tests included angles rarely observed in rugby league, these tests remained. Finally, no sport-specific measure of prolonged high-intensity intermittent running was available with running-based tests previously used and their suitability for rugby questioned.[9,92] For these reasons, combined with anecdotal evidence from coaches and players, this test remained but the physiological responses and concurrently validity required investigation. There was an overall lack of procedural details reported across the literature included in this review, making it difficult to standardise and interpret results. Therefore, this research seeks to provide sufficient details to allow practitioners in rugby league to use this battery with minimal self-interpretation. Finally, with the standardised battery confirmed, the reliability, discriminant validity and sensitivity required investigation before being implemented by UK-based rugby league clubs.

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Chapter 3

The reliability of the Rugby League Athlete Profiling (RLAP) battery for assessing the physical characteristics of rugby league players

The systematic review in Chapter 2 highlighted that a large number of performance tests were available to practitioners for evaluating the anthropometric and physical characteristics of rugby league players. However, it was also noted that, for a large number of tests, the reliability of the outcome variable was unknown. The original battery of tests proposed by the RFL included several tests that has received little or no consideration with regards to the reliability. For example, the reliability of the change of direction test, sport-specific Yo-Yo IR1 and medicine ball throw was unknown. Further, the review highlighted how only one study reported the smallest worthwhile change in performance, with this limited to linear sprinting and was only based on two trials and a small sample size. Therefore, Chapter 1 sought to determine the reliability of each test in the RLAP battery using three trials and the minimum recommended sample of 50 participants.

Dobbin, N., Hunwicks, R., Highton, J., & Twist, C. (2018). A reliable testing battery for assessing physical qualities of elite academy rugby league players. *Journal of Strength and Conditioning Research, 32*(11), 3232-3238.

3.1 Introduction

Rugby league is an intermittent collision sport that requires players to perform frequent high-intensity movements such as high-speed running, sprinting, and tackling interspersed with periods of low-intensity activities such as standing, walking, and jogging.[98] As such, players are required to possess highly developed physical characteristics including speed, strength, power, agility and endurance as well as skill and tactical awareness.[13,96,116] The assessment of these physical characteristics can provide objective data that can be used to ensure players can meet the demands of the sport,[96] evaluate adaptation to training programmes,[98] identify talent,[94,98] monitor player development[255] and predict player selection.[13]

Linear sprint ability is frequently assessed by rugby league practitioners and used in combination with body mass to determine a player's sprinting momentum, evaluate training adaptation and monitoring development.[255] Furthermore, sprinting ability appears to be an integral component for successful performance in rugby league, with players performing an average 35 ± 2 sprints per match over distances up to 20 m.[100] These actions often occur during critical passages of play such as scoring or conceding a try.[91] Consequently, rugby league players' sprint performance is typically measured over 10-, 20-, and 40 m distances, though the inclusion of 40 m is questionnionale.[56] Sprint speed is reported to improve from off-season to mid-season in junior rugby league players[98] and can discriminate between playing standards (e.g. professional, semi-professional and amateur).[99] Therefore, the ability to assess these characteristics in the context of a practically meaningful change in acceleration and maximal speed is essential for rugby league practitioners.

The ability to change direction is also an essential quality in rugby league that discriminates between playing standards.[94] Several change of direction tests have been used in rugby league; these include the Illinois agility test,[94] 'L'-run,[98,124] and 505 agility.[124] However, no rugby-league specific test is universally advocated and those used typically focus on change of direction angles above 90° rather than incorporating 'cutting'; a skill often performed during rugby league match-play.[124]

Well-developed muscular power in rugby league has been associated with successful skill execution[265] and reduced post-match fatigue.[169] Accordingly, practitioners at all standards of the game must be able to assess power using practical methods of assessment. Several methods have been employed to assess upper- and lower-body power in rugby league players, including, but not limited to, the jump squat,[12] CMJ,[265] medicine ball throw[243] and bench press throw.[12] While the medicine ball throw and vertical jump do not provide direct measures of muscle power, both tests are valid measures of this physical charcteristic[163] and are easy and quick to administer. Scores obtained using the medicine ball throw and CMJ can differentiate between national and regional youth rugby league players.[243]

The Yo-Yo IR1 and $30\text{-}15_{IFT}$ are often used to assess intermittent running capacity of rugby league players.[5,219] Using the Yo-Yo IR1 to differentiate between low- and high-fitness players, Johnston et al.[169] reported that the high-fitness group covered significantly greater distances at high- and very high-speeds during match-play as well as improved recovery. In contrast, no significant relationship was observed between Yo-Yo IR1 and measures of physical match performance in semi-professional rugby league players.[92] It is known that the collision contributes to a greater physiological load,[204] which might result in a disassociation between physical match performance and a running-based intermittent field test.[10] As such, an up-and-down action at the start of each shuttle was included to assess the players' ability to get up after the tackle and join play.

Whilst a range of physical characteristics seem important in rugby league, the results of the systematic review highlighted a wide range of tests currently available to practitioners and researchers. In light of this, it is difficult to compare players between age-grades, clubs and countries. As such a standardised battery of tests that is suitable for all rugby league athletes and that is easily replicable could be useful.[255] The RFL provided a standardised battery (SPARQ) of tests to be used with UK-based youth, academy and senior rugby league players. Based on the results of the systematic review, a measure of speed over a short (< 20 m) distance would be worthwhile, that no rugby-specific intermittent fitness test currently exists and that change of direction tests rarely measures cutting ability, aspects of the SPARQ battery were altered and those that were justified by the review were kept, with the whole battery renamed the RLAP battery. Whilst the RLAP battery was economical, easy to administer, requires minimal technical equipment or expertise, it is important to ensure that all tests included in the RALP battery are reliable.[7] The reliability, expressed as a coefficient of variation, for the 10 m (3.05%) and 20 m (1.82%) sprint times (11), CMJ height (5.2%) (9), Yo-Yo IR1 (8.7%)[238] and pre-planned agility (1.9-2.5%)[124] has been reported using team sport athletes. However, few studies have established the reliability using only rugby league players, which is important given the large differences in physical attributes (i.e. body mass) compared to other team sports. Furthermore, previous reliability studies have typically used small sample sizes (< 50) over two repeated trials. Hopkins[145] noted that to achieve reasonable precision for estimates of reliability, approximately 50 participants and at least three trials are required. Understanding the reliability of a range of performance tests used in rugby league and the extent to which players require habituation (as determined by a third trial) would therefore be practically meaningful. Accordingly, this study sought to assess the inter-day reliability, in the context of meaningful changes in performance, of the RLAP battery that can be used to assess the physical characteristics of rugby league players.

3.3. Methods

3.3.1. Participants

With institutional ethics approval, 50 academy rugby league players from three professional clubs playing in the under-19s Super League competition (age 17 ± 1 years; stature 181.3 ± 6.3 cm; body mass 89.0 ± 11.6 kg) participated in the study. Players were informed of the benefits and risk associated with this study before providing written informed consent and completing a pre-test health questionnaire. Parental consent also provided for all participants <18 years old. Players were free from injury at each time point of the study, which was confirmed by the respective club's medical team.

3.3.2. Study design

The repeated measures design required participants to complete the RLAP battery on three separate occasions with 7.9 ± 3.8 (range 5-14) days between visits. All visits took place during each club's pre-season with players performing no work-based or leisure-time physical activity in the 24 h before data collection. On arriving at the club's own training facility, measures of stature (SECA stadiometer, Leicester Height Measure, Hamburg, Germany) and body mass (SECA scales, 813, SECA, Hamburg, Germany) were recorded before performing a CMJ, 10 and 20 m sprint test, change of direction test, medicine ball throw and modified Yo-Yo IR1 (prone Yo-Yo IR1). All tests were carried out by the same researcher and were performed on an outdoor synthetic grass pitch (3G all-weather surface) at the same time of day (± 2 h), with a mean temperature during the three trials of 10.8 ± 3.8°C. Participants were asked to refrain from caffeine 12 hours before testing, and although not measured, were advised to attend each session well-hydrated. Participants were required to wear the same clothing and footwear (studded boots) for each visit and completed a standardised warm up before being divided into two groups. Group one completed the CMJs and sprint tests, while group two completed the medicine ball throw and change of direction test. The groups then swapped and came together to complete the prone Yo-Yo IR1. The test order was standardised for all visits and was completed within ~75 min.

3.3.3. Procedures

Countermovement jump

Participants completed four CMJs comprising two using their arms (with) to determine the influence of the arm swing on measures of reliability and two with hands placed on the hips (without) in an attempt to standardise the jump. A period of 2-minutes recovery was permitted between jumps. Participants started in an upright position before flexing at the knee to a self-selected depth and then extending into the jump for maximal height keeping their legs straight throughout. All jumps were performed in the same playing kit with playing boots on. Jumps that did not meet the criteria were not recorded and participants were asked to complete an additional jump. Jump height was recorded using a jump mat (Just Jump System, Probotics, Huntsville, Alabama, USA) with scores corrected (Appendix 11) before peak height was used for analysis.

Sprint performance and momentum

Sprint performance was measured using single beam electronic timing gates (Brower, Speedtrap 2, Brower, Utah, USA) positioned at 0, 10 and 20 m. The timing gates were placed 150 cm apart and at a height of 90 cm for all trials. Participants began each sprint from a two-point athletic stance with their driving foot placed 30 cm behind the start line. Participants performed two maximal 20 m sprints recorded to the nearest 0.01 s with 2-minutes recovery between each. The best 10 and 20 m sprint times were used for analysis. Momentum was calculated by multiplying body mass by mean velocity (distance / time) over the best 10 and 20 m time recorded.[61]

Change of direction

Change of direction performance was measured using single beam electronic timing gates (Brower, speedtrap 2, Brower, Utah, USA) placed 150 cm apart and at a height of 90 cm, and required participants to complete two trials (left and right) consisting of different cutting manoeuvres over a 20 x 5 m course (Figure 10). Participants started when ready from a two-point athletic stance with their driving foot placed 30 cm behind the start line. One trial was performed on the left, the timing gates were then moved, and a second trial was performed on the right in a standardised order before times were combined. Failure to place both feet around each cone resulted in disqualification and participants were required to repeat the trial.

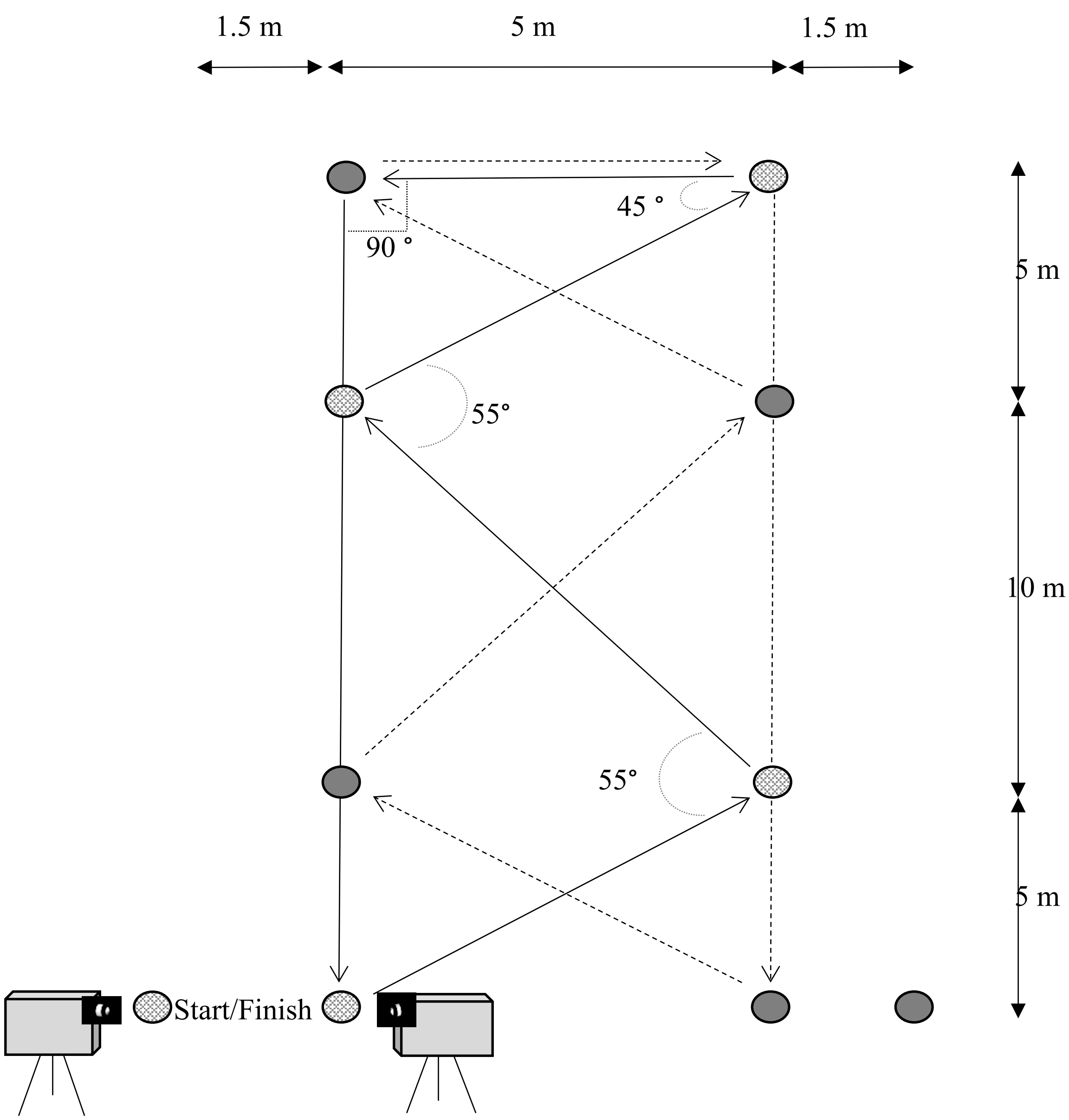

Figure 10. Schematic representation of the change of direction test.

Medicine ball throw

Whole-body muscle function was assessed by having participants throw a medicine ball (dimensions: 4 kg, 21.5 cm diameter) striving for maximum distance. Participants began standing upright with the ball above their head. They then lowered the ball towards their chest whilst squatting down to a self-selected depth before extending up onto their toes and pushing the ball as far as possible. Feet remained shoulder width apart, stationary and behind a line that determined the start of the measurement. The distance was measured to the nearest centimetre using a tape measure from the line on the floor to the rear of the ball's initial landing position. A trial was not recorded if the participant stepped into the pass, jumped or if the ball landed outside of the measuring area and, in such cases, an additional trial was completed. Participants completed two trials separated by 2-minutes recovery with the furthest distance used for analysis.

Prone Yo-Yo Intermittent Recovery Test Level 1

The prone Yo-Yo IR1 was used to measure high-intensity intermittent running capacity and required participants to complete as many 40 m shuttles as possible with a 10 s active recovery (walking) between shuttles.[23] Running speed for the test commenced at 10 $km \cdot h^{-1}$ and increased 0.5 $km \cdot h^{-1}$ approximately every 60 s to the point at which the participants could no longer maintain the required running speed. Participants were required to start each shuttle in a prone position and were allowed two practice shuttles before starting the test. The final distance achieved was recorded after the second failed attempt to meet the start/finish line in the allocated time.

3.3.4. Statistical analysis

Data are presented as mean ± SD. The distribution of each variable was examined using the Shapiro-Wilk normality test and homogeneity of variance was verified with the Levene test. To determine if there was a systematic difference between trials, separate repeated measure ANOVA were performed with alpha set at 0.05 and *non-significance* interpreted as a lack of systematic performance improvement or decrement rather than no difference between trials. In the presence of a statistically significant difference, *post-hoc* paired samples *t*-tests were performed with Bonferroni adjustment. To determine the reliability of each measure, intraclass correlation coefficient (ICC) with 95% confidence limits (CL), typical error (TE) and coefficient of variation (CV%) with 90% CL were used. TE was calculated as the standard deviation of the differences between trials divided by the √2 and the CV% as (TE / grand mean) x 100. Standardised changes of different magnitudes were calculated to provide context for the observed inter-day variation in measurements. A smallest worthwhile change (SWC) in performance was considered as 0.2 x the pooled standard deviation for each variable.[24,153] To ascertain the performance improvement required to be 75% confident the change was beneficial,[134] a magnitude-based inferences approach was used using the SWC and TE for each variable[144] and reported as the required change. These required performance improvements are presented in the results and are later used as an 'analytical goal' (i.e. the observed reliability must be sufficient to allow confident detection of feasible or previously observed changes in performance). Statistical analyses were conducted using SPSS for Windows (Version 22.0, 2013) and a pre-designed spreadsheet.[149]

3.4. Results

There was no systematic change for tests except the medicine ball throw. Inter-day reliability of the performance tests across the three trials is presented in Table 4. While none of the variables had a TE less than the SWC all variables had a TE less than that typically observed after a pre-season season training period or intervention. All tests had a CV of less than 10% with the change of direction test (2.4%) and 20 m sprint tests (3.6%) demonstrating the lowest and prone Yo-Yo IRT1 (9.9%) the highest variability. ICC ranged from 0.74 and 0.98 and the required change for all performance tests with 75% confidence are presented in Table 4.

Between-day comparisons indicated that medicine ball throw distance was greater on trial 2 ($P < 0.05$) compared to trials 1 and 3. Performance during all other tests did not systematically change across trials ($P > 0.05$). Specific comparisons of variability between days indicated that reliability was, for the most part, best when comparing trials 1 and 2 (Table 5).

Table 4. Inter-day reliability of performance variables from the RLAP battery

Test	Trial 1	Trial 2	Trial 3	ICC (95% CL)	TE (90% CL)	SWC	CV% (90% CL)	Required change
10 m sprint (s)	1.90 ± 0.11	1.95 ± 0.12	1.92 ± 0.13	0.81 (0.70-0.89)	0.08 (0.07-0.09)	0.03	4.2 (3.8-4.8)	0.11
20 m sprint (s)	3.23 ± 0.20	3.25 ± 0.15	3.27 ± 0.17	0.78 (0.65-0.87)	0.11 (0.10-0.13)	0.04	3.6 (3.1-4.2)	0.15
10 m momentum ($kg \cdot m \cdot s^{-1}$)	468 ± 52	460 ± 53	466 ± 51	0.91 (0.85-0.94)	25 (21.91-28.71)	10	5.5 (4.8-6.4)	34
20 m momentum ($kg \cdot m \cdot s^{-1}$)	489 ± 31	484 ± 23	482 ± 25	0.86 (0.78-0.92)	14 (12.75-16.79)	5	3.1 (2.7-3.6)	19
Jump Height [a] (cm)	41.6 ± 5.7	41.4 ± 5.8	41.1 ± 5.3	0.92 (0.87-0.95)	2.4 (2.1-2.8)	1.1	6.2 (5.4-7.2)	3.4
Jump Height [b] (cm)	34.8 ± 4.8	35.0 ± 5.0	34.8 ± 4.8	0.94 (0.91-0.97)	2.0 (1.8-2.3)	1.0	5.9 (5.2-6.8)	2.9
COD *left* (s)	10.39 ± 0.36	10.31 ± 0.43	10.26 ± 0.45	0.86 (0.77-0.92)	0.24 (0.22-0.27)	0.08	2.4 (2.1-2.7)	0.31
COD *right* (s)	10.37 ± 0.47	10.30 ± 0.55	10.28 ± 0.49	0.89 (0.83-0.94)	0.26 (0.24-0.30)	0.10	2.5 (2.3-2.9)	0.35
COD *total* (s)	20.76 ± 0.92	20.61 ± 0.96	20.54 ± 0.89	0.92 (0.87-0.95)	0.52 (0.46-0.60)	0.18	2.5 (2.2-2.9)	0.67
Medicine ball throw (m)	6.4 ± 0.8†	6.9 ± 0.7*§	6.6 ± 1.0†	0.74 (0.57-0.84)	0.5 (0.4-0.6)	0.2	9.0 (7.9-10.5)	0.7
Prone Yo-Yo IR1 (m)	766 ± 232	759 ± 246	762 ± 245	0.98 (0.96-0.99)	66 (59-77)	48	9.9 (8.7-11.6)	120

*[a] with arms. [b] without arms. COD = change of direction. ICC = intraclass correlation coefficient. TE = typical error. SWC = smallest worthwhile change (0.2 x pooled SD). CV% = coefficient of variation. Required change = change in performance with 75% confidence that the change is beneficial. *Significantly (P < 0.05) different to trial 1, †significantly different to trial 2, §significantly difference to trial 3.*

Table 5. Inter-day comparisons of performance variables. Values are ICC with 95% CL, and TE and CV with 90% confidence limits in parentheses.

	Trial 1 - 2			Trial 1 - 3			Trial 2 - 3		
	ICC	TE	CV%	ICC	TE	CV%	ICC	TE	CV%
10 m sprint (s)	0.76 (0.55-0.87)	0.07 (0.06-0.08)	3.5 (3.0-4.3)	0.77 (0.60-0.87)	0.08 (0.07-0.09)	4.2(3.6-5.1)	0.69 (0.46-0.82)	0.09 (0.08-0.11)	4.9 (4.2-6.0)
20 m sprint (s)	0.79 (0.63-0.88)	0.11 (0.09-0.13)	3.3 (2.9-4.0)	0.68 (0.44-0.82)	0.13 (0.11-0.15)	4.1 (3.5-4.9)	0.62 (0.33-0.78)	0.12 (0.10-0.14)	3.8 (3.3-4.6)
10 m momentum ($kg \cdot m \cdot s^{-1}$)	0.87 (0.79-0.93)	24 (21-29)	5.2 (4.5-6.3)	0.86 (0.75-0.92)	26 (22-31)	5.7 (4.9-6.9)	0.86 (0.76-0.92)	25 (22-30)	5.6 (4.8-6.8)
20 m momentum ($kg \cdot m \cdot s^{-1}$)	0.86 (0.75-0.92)	13 (11-15)	2.7 (2.3-3.2)	0.81 (0.67-0.89)	15.0 (13-18)	3.2 (2.7-3.9)	0.74 (0.54-0.85)	16 (14-19)	3.4 (2.9-4.1)
Jump Height [a] (cm)	0.89 (0.80-0.94)	2.6 (2.2-3.1)	6.8 (5.8-8.3)	0.84 (0.72-0.91)	2.9 (2.50-3.50)	7.3 (6.2-8.8)	0.92 (0.86-0.95)	2.2 (1.9-2.6)	5.5 (4.7-6-6)
Jump Height [b] (cm)	0.95 (0.92-0.97)	1.5 (1.3-1.8)	4.4 (3.8-5.3)	0.92 (0.86-0.96)	2.4 (2.0-2.9)	7.1 (6.0-8.6)	0.87 (0.78-0.93)	1.9 (1.6-2.3)	5.7 (4.8-6.9)
COD *left* (s)	0.80 (0.64-0.88)	0.24 (0.20-0.29)	2.3 (2.0-2.8)	0.82 (0.69-0.90)	0.23 (0.19-0.27)	2.1 (1.9-2.7)	0.78 (0.63-0.88)	0.26 (0.22-0.31)	2.5 (2.2-3.1)
COD *right* (s)	0.84 (0.72-0.91)	0.27 (0.23-0.32)	2.6 (2.2-3.1)	0.88 (0.80-0.93)	0.22 (0.19-0.27)	2.3 (1.9-2.6)	0.82 (0.68-0.90)	0.29 (0.25-0.35)	2.8 (2.4-3.4)
COD *total* (s)	0.89 (0.81-0.86)	0.52 (0.45-0.63)	2.5 (2.2-3.0)	0.90 (0.82-0.94)	0.48 (0.41-0.58)	2.3 (2.0-2.8)	0.86 (0.75-0.92)	0.52 (0.44-0.62)	2.5 (2.2-3.1)
Medicine ball throw (m)	0.71 (0.28-0.86)	0.5 (0.4-0.5)	6.9 (5.8-8.3)	0.50 (0.11-0.71)	0.7 (0.60-0.85)	14.0 (11.9-17.1)	0.73 (0.50-0.85)	0.5 (0.43-0.60)	10.7 (9.1-13.1)
Prone Yo-Yo IR1 (m)	0.97 (0.94-0.98)	62 (53- 74)	9.7 (8.3-11.9)	0.97 (0.94-0.98)	64 (55-77)	8.5 (7.3-10.4)	0.96 (0.93-0.98)	71 (61-85)	10.1 (8.6-12.3)

[a] *with arms.* [b] *without arms. COD = change of direction. ICC = intraclass correlation coefficient. TE = typical error. CV% = coefficient of variation. SWC = smallest worthwhile change (0.2 x pooled SD of scores for that variable).*

3.5. Discussion

The purpose of this study was to determine in inter-day reliability of the RLAP battery for the assessment of physical characteristics. Overall, the variability exceeded the statistically determined SWC in performance but was less than that typically observed after a pre-season training period or intervention. This suggests the RLAP battery used can detect a meaningful change with 75% confidence comparable to that typically observed or that is considered feasible. The RLAP battery was efficient, simple to administer and required minimal equipment and expertise; thus, enables rugby league practitioners to use our results when interpreting differences between players and for assessing the effectiveness of training programmes.

The reliability of 10 and 20 m sprint times was similar to that previously reported (4.2% *cf.* 3.1% and 3.6% *cf.* 1.8%, respectively).[61] However, it is important to note that the study by Darrall-Jones et al.[61] used a combination of rugby league and rugby union players who likely present different anthropometric characteristics and running mechanics.[56] The TE for 10 and 20 m sprint times was greater than the SWC for both distances; however, when considering the reliability of sprint performance against previously reported improvements, both distances appear sensitive enough to detect the observed change (TE 0.08 *cf.* 0.13 s; CV 4.2% *cf.* 7.3%) after an 8-week pre-season training period in professional rugby league players.[47] Indeed, using a magnitude-based inferences approach our analysis revealed that the required change was lower than the improvement observed over 10 (0.11 *cf.* 0.13 s) and 20 m (0.15 cf. 0.18 s) after an 8-week strength and power pre-season training block.[47] Inter-day comparisons for 10 and 20 m sprint performance were best between trials 1 and 2, suggesting that habituation to sprint tests is not required with academy rugby league players.

To the author's knowledge, this is the first report of between-session reliability for momentum in professional rugby league players. The TE for 10 and 20 m momentum was greater than the SWC. Nonetheless, based on the mean body mass (96.2 ± 11.11 *cf*. 97.7 ± 11.13 kg), 10 m sprint times (1.78 ± 0.07 cf. 1.65 ± 0.08 s) and 20 m sprint times (3.03 ± 0.09 *cf.* 2.85 ± 0.11) reported by Comfort et al.[47] before and after 8 weeks of pre-season strength and power training, changes in momentum would be of greater magnitude than the TE (52 and 51 *cf.* 25 $kg \cdot m \cdot s^{-1}$, respectively) and CV% (9.6 and 8.0 *cf.* 5.5%, respectively) reported in this study. Our results revealed that a 34 and 19 $kg \cdot m \cdot s^{-1}$ improvement over 10 and 20 m, respectively, is required to be 75% confident the change is meaningful,[146] which could feasibly be achieved through a reduction in sprint times or an increase in body mass. These results, combined with the inter-day comparisons, suggest that momentum could be a useful measure for practitioners in rugby league to assess the combined effect of an individual's body mass and sprint capability over 10 m and 20 m.

These data indicate that the CMJ is a reliable measure of lower-body muscle function and is improved when a participant's hands remain on their hips (CV% = 5.9% *cf.* 6.2%). The use of an arm swing during jumping can improve jump height due to an increased release velocity and centre of mass.[181] The use of arms allows the athlete to use energy in the elbow, shoulder and hip to increase the kinetic energy at take-off and increase the vertical 'pull' on the trunk.[181] However, with the added movement complexity, the arm swing increases the within-participant variability between jumps.

These results also indicate that reliability was best for CMJ with arms between trials 2 and 3 suggesting that habituation is required. Overall, the CV% for CMJ without arms are similar to that reported by Cormack et al.[53] and is smaller than typical improvements in jump performance observed in young (7.2%) but not senior (4.5%) team sport players after pre-season training.[116] Furthermore, these data revealed that the TE is sufficient to confidently detect a change (3.4 cm) which is less than that previously observed in junior rugby players after a 14-week pre-season training programme (~4.2 cm) (16). Inter-day reliability for CMJ without arms was best between trials 1-2 suggesting that habituation is not required when using academy rugby league players.

The medicine ball throw has been used as a measure of whole-body muscle function in rugby players that is valid and reliable.[233] However, it is important to note that several techniques have been adopted. The present study required participants to throw a medicinal ball from the chest in a standing position to better replicate the upper-body actions of rugby league, e.g. a 'hand-off'. The variability was greater than the SWC in medicine ball throw performance, whilst an increase of 0.7 m in distance would be required to ensure an improvement is beneficial with a certainty of 75%.[146] As the TE was greater than the SWC, practitioners who want to use the medicine ball throw should consider incorporating this into training to regularly assess whole-body power.[135,146] The reliability of the medicine ball throw was likely influenced by use of the lower-body as well as the lack of control over the release angle. Notwithstanding this, using the results of Speranza et al.[232] who reported an increase in plyometric push-up performance of 11.9% after an 8-week pre-season training period in semi-professional rugby league players, the medicine ball throw could detect large changes

(>0.7 m) in whole-body muscle function, albeit further research is required to confirm this.

These results indicated good reliability for the change of direction test, albeit the variability exceeded what is considered the SWC in left, right and total time. Nonetheless, the variability is less than the typical change (junior = 17.7% and senior 16.3%) in ‘L run’ times after a 14-week pre-season period using rugby league players.[116] To achieve 75% confidence, an improvement of -0.31, -0.35 and -0.67 s for left, right and total change of direction times, respectively, is required. However, directly comparing the absolute change required against that previously observed is difficult given the novelty of the test used and further research might reaffirm this. Inter-day comparisons revealed that the reliability was similar between all trials but was lowest between days 1 and 3 for left, right and total time, suggesting habituation to this test might be required. The change of direction test used in this study assesses a player’s ability to change direction over several angles that better replicates the movement characteristics during intermittent team sport.

The variability associated with the prone Yo-Yo IR1 was greater than that considered to be the SWC in performance. The required change in individual performances when accounting for the TE corresponded with a 120 m (or 3 shuttles) increase in performance to be considering meaningful.[135] To date, no research has reported the change in Yo-Yo IR1 performance after a training intervention or pre-season training period using rugby league players. However, Bangsbo et al.[23] reported changes of between 12.7-31.1% after 6- to 12-weeks of soccer-specific, interval and repeated sprint training, a change that could confidently be detected with our reported TE. Whilst practitioners might use the reliable Yo-Yo IR1 for assessment of running alone, the modified Yo-Yo presented here offers an opportunity to assess high-intensity intermittent running incorporating a sport-specific task with sufficient reliability.

While every effort was made to reduce the contribution of fatigue by conducting tests on the day after a scheduled rest day, collecting data during pre-season means players were likely to be subject to higher training volumes than other times of the year.[89] Therefore, it is possible that some residual fatigue from training several days beforehand each test might have contributed to a larger variability between trials. Future research might consider using perceptual measures of fatigue to quantify recovery status when establishing the inter-day reliability of this battery of tests. This notwithstanding, these data are taken from a large sample size within a professional training environment that reflects the real-world variability in performance. It also noteworthy that the test order was different for the two groups although results (not reported) revealed minimal difference in reliability (for example, 10 m sprint time: group 1; TE = 0.08 and CV = 4.5%, and group 2; TE = 0.08 and CV = 3.9%). We would, however, recommend that practitioners perform the testing in the following order to minimise any influence of residual fatigue on test performance: warm up, sprint test and CMJ, and change of direction test, and medicine ball throw then completing the prone Yo-Yo IR1.

3.6 Conclusions and practical applications

These results support the interpretation of tests of physical characteristics and provide a novel approach using magnitude-based inferences. All performance tests demonstrate acceptable reliability in the context of detecting a typical change after a training intervention or pre-season training period using rugby league players. However, the variability associated with each performance measure, when tested in the ‘field’, was greater than that required to detect the smallest worthwhile change in performance. Practically, this means that practitioners are not able to detect small but potentially meaningful changes in these physical characteristics with any confidence given the change might be a reflection of the random error. As such these small but potentially meaningful changes might go undetected until a large enough change can be observed with certainty. Between-trial comparisons revealed that, for the most part, habituation was not required when using rugby league players. Due to the large between-trial variation during the medicine ball throw, researchers might wish to investigate the reliability and sensitivity of the medicine ball throw when controlling variables such as release angle. Results also revealed that the reliability of the CMJ was improved when participants placed their hands on their hips and that the between-trial reliability of momentum was acceptable and can be used to assess the relationship between body mass and 10 and 20 m sprint capacity. Future research should establish the usefulness of the RLAP battery to monitor changes in players’ physical characteristics over a season or during specific training periods (e.g. pre-season). Where time and resources are scarce, the RLAP battery can be conducted in a relatively short time frame (<75 min), does not impact on other training and requires minimum specialist equipment.

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Chapter 4

The discriminant validity of the Rugby League Athlete Profiling (RLAP) battery and its ability to differentiate anthropometric and physical characteristics between youth, academy and senior professional rugby league players.

The ability of some anthropometric and physical characteristics to discriminate between playing standards was noted in Chapter 2 with a small mean effect size observed for stature, linear sprinting and jump height. However, the validity of the change of direction test, medicine ball throw and prone Yo-Yo IR1 was unknown. Furthermore, information on the discriminant validity of an entire battery was limited along with insight into the accuracy of group allocation. Of those studies that reported the discriminant validity, none included the reliability within the interpretation. The results of Chapter 3 provided a single value that included the typical error and worthwhile change/difference that could be used in the interpretation of the difference between playing standards. Finally, as noted in the Introduction, an RFL objective of this project was to establish position-specific normative data of UK-based rugby league players. Therefore, Chapter 4 sought to determine the discriminant validity of the RLAP battery with the magnitude of difference interpreted using the required change reported in Chapter 3 as well as establish position-specific normative data for youth, academy and senior players.

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4.1. Introduction

In an attempt to improve sporting success at both club and national standards, governing bodies such as the RFL have resourced Talent Identification and Development (TID) programmes to aid selection and training processes for young 'talented' players.[242] Clubs are also encouraged to develop young players, with financial incentives offered by the governing body that lifts salary restrictions on players eligible for both academy and senior rugby. This, in theory, offers young players a pathway into senior rugby league while allowing financially inferior teams to supplement their squad with "home grown" talent.[75] In rugby league, the majority of professional clubs run a TID programme, whereby players aged between 14 and 15 and those between 16 and 18 years are contracted to scholarship and academy teams, respectively.[264] Such programmes are designed to recognise players with potential, enabling them to excel early in their development[247,259,272] via appropriate coaching, welfare, and sport science provision.[259,125]

Entry onto a TID programme is multidimensional and typically includes physical, technical, tactical, social and perceptual skills[37,2597,272] as well as consideration for maturation.[37,75,247] The anthropometric and physical characteristics of rugby league players appear important and can discriminate between playing standards,[13,93] positions,[99,198] those selected and not-selected onto a TID programme[257] and age categories.[255] For example, Tredrea et al.[257] observed that those players selected onto a TID programme were faster and more powerful than non-selected players. Till et al.[246] also reported that a combination of anthropometric and physical characteristics accurately discriminated between amateur and professional status in rugby league (sensitivity >83%). Collectively, these studies indicate anthropometric and physical characteristics can be used to make informed decisions on a player's progression and development as well as identifying 'talent'; albeit, the need for reliable measures of anthropometric and physical characteristics that can discriminate between standards (i.e. discriminant validity) are required.[75,264]

The majority of studies to date examining the anthropometric and physical characteristics of rugby league players have collected data from a single club with relatively small sample sizes.[94,124,257] These limitations could be addressed with a the RLAP battery that provides normative data on physical characteristics for youth, academy and senior rugby league players from multiple clubs. To this end, a reliable battery of tests was recently introduced that enabled youth, academy and senior players to be assessed efficiently using the same procedures with minimal cost (Study 1). What remains unclear is how the specific components of this battery differentiate between performance standards in male rugby league players and the discriminant validity of the RLAP battery as a whole. Accordingly, this study aimed to investigate differences in anthropometric and physical characteristics between youth, academy and senior rugby league players across multiple clubs and establish the discriminant validity the RLAP battery. In an attempt to fulfil one of the RFL's objectives for this project, this study also sought to establish normative data across playing standards with reference to playing position

4.2. Methods

4.2.1. Participants

With institutional ethics approval, 729 male youth (*n* = 235), academy (*n* = 362) and senior (*n* = 132) rugby league players from 12 individual clubs participated in the study

(Table 1). Youth players were affiliated with a scholarship programme and academy players were contracted to a professional club. Senior players were professional and had competed at least one full competitive season in the European Super League. Players at each standard were classified as back row forwards, props, hookers, halves, centres and fullback/winger and was based on the position they played most often.[198]

4.2.2. Study design

Using an observational study design, participants completed the RLAP battery during the first two weeks of the Super League pre-season. First they completed measures of stature to the nearest 0.1 cm (Seca, Leicester Height Measure, Hamburg, Germany) and body mass to the nearest 0.1 kg (Seca, 813, Hamburg, Germany) wearing minimal clothing and no footwear before commencing the RLAP. All testing, which took place at the club's own training ground on artificial turf, was preceded by 48 hours of no leisure- or club-based physical activity and participants were instructed to arrive in a fed and hydrated state. All participants were familiar with the procedures having completed these tests before as part of routine club monitoring activities.

4.2.3. Procedures

During each performance testing session, participants were divided into two equal groups with group one completing the sprint and CMJ test whilst group two completed the change of direction test and medicine ball throw. The groups then swapped and came together to complete the prone Yo-Yo IR1. The testing procedures were in accordance with those outlined in Chapter 3. All measures were conducted by the same researcher in a standardised order and with no verbal encouragement provided.

4.2.4. Statistical analysis

Data are presented as mean ± SD. Magnitude-based inferences and effect sizes (ES) with 90% confidence limits were used, with ES calculated as the difference between groups divided by the pooled SD. Threshold values for effect sizes were: 0.0-0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; >2.0, very large.[152] Threshold probabilities for a mechanistic effect based on the 90% confidence limits were: 25-75% possibly, 75-95% likely, 95-99% very likely and > 99.5 most likely.[25] Effects with confidence limits spanning a likely small positive or negative change were classified as unclear. Interpretation about the magnitude of difference was also assessed with reference to the required change (TE + SWC) for each test (Chapter 3). Statistical analysis was conducted using a predesigned spreadsheet for independent groups.[145] To identify which measures included in the RLAP battery discriminate between youth, academy and senior players, a stepwise discriminant analysis was applied with playing standard included as the dependent variable and performance tests as predictor variables. The ability for each physical characteristic included in the model to separate the playing groups was demonstrated using the Wilks lambda (λ) with a value of 0 meaning the groups are completely separated and a 1 meaning the groups are poorly separated based on the characteristics in question. To ascertain the accuracy of the classification model and error rate, a leave-one-out method was employed whereby the one sample is omitted from the group prediction and then using this model the omitted sample's group is predicted. This process is then repeated with an overall error rate (i.e. incorrect allocation) determined. Analysis was performed using SPSS version 25 with alpha set at 0.05.

4.3. Results

Analysis revealed *trivial* to *very large* differences between playing standards in several anthropometric and physical characteristics (Table 6). Compared to youth players, academy and senior players were most likely taller and heavier, with senior players likely taller and most likely heavier than academy players. Differences in 10 and 20 m sprint times were likely trivial between youth and academy players but were possibly to very likely lower for senior players compared to youth (20 m only) and academy players. CMJ height was most likely higher for academy players compared to youth, and most likely higher for senior players compared to youth and academy players. Differences in change of direction time were likely trivial between youth and academy, and most likely faster for senior players. Medicine ball throw distance for senior was most likely higher compared to youth and academy, and most likely higher for academy compared to youth players. Prone Yo-Yo IR1 distance was most likely higher for senior players compared to youth and academy players, with distance possibly higher for academy compared to youth.

Normative data for each playing position at youth, academy and senior standard are presented in Table 7, with the magnitude of differences presented in Figure 11. Within-positional group differences ranged from *trivial* to *very large*, and for the most part, indicated that the differences between senior and academy players was smaller than between senior and youth players.

Table 6. Anthropometric and physical characteristics for youth, academy and senior rugby league players.

	Performance standard			Effect size ± 90% CI		
Characteristic	Youth (*n* = 235)	Academy (*n* = 365)	Senior (*n* = 132)	Youth *cf.* Academy	Youth *cf.* Senior	Academy *cf.* Senior
Age (years)	15.1 ± 0.8	17.5 ± 2.0	23.7 ± 4.3	2.65 ± 0.17 *Most likely ↑*	8.11 ± 0.48 *Most likely ↑*	3.60 ± 0.32 *Most likely ↑*
Stature (cm)	172.6 ± 6.9	180.7 ± 6.4	182.7 ± 5.8	0.64 ± 0.13 *Most likely ↑*	0.92 ± 0.16 *Most likely ↑*	0.32 ± 0.15 *Likely ↑*
Body mass (kg)	73.6 ± 10.6	87.5 ± 11.7	95.6 ± 10.0	1.21 ± 0.13 *Most likely ↑*	1.84 ± 0.15 *Most likely ↑*	0.70 ± 0.14 *Most likely ↑*
10 m sprint (s)	1.83 ± 0.11	1.84 ± 0.11	1.82 ± 0.09	0.14 ± 0.13 *Likely trivial*	-0.06 ± 0.16 *Likely trivial*	-0.21 ± 0.15 *Possibly ↓*
20 m sprint (s)	3.16 ± 0.16	3.15 ± 0.16	3.09 ± 0.12	-0.06 ± 0.14 *Likely trivial*	-0.42 ± 0.16 *Very likely ↓*	-0.35 ± 0.14 *Very likely ↓*
CMJ height (cm)	33.3 ± 6.8	38.1 ± 6.3	42.5 ± 5.2	0.63 ± 0.12 *Most likely ↑*	1.12 ± 0.12 *Most likely ↑*	0.70 ± 0.14 *Most likely ↑*
Change of direction (s)	20.31 ± 1.22	20.44 ± 1.30	19.68 ± 0.84	0.10 ± 0.13 *Likely trivial*	-0.46 ± 0.14 *Most likely ↓*	-0.60 ± 0.13 *Most likely ↓*
Medicine ball throw (m)	6.3 ± 0.9	7.1 ± 0.8	8.1 ± 0.8	1.00 ± 0.14 *Most likely ↑*	2.06 ± 0.16 *Most likely ↑*	1.12 ± 0.15 *Most likely ↑*
Prone Yo-Yo IR1 (m)	727 ± 252	775 ± 233	930 ± 277	0.23 ± 0.13 *Possibly ↑*	0.74 ± 0.16 *Most likely ↑*	0.61 ± 0.17 *Most likely ↑*

Data are presented as mean ± SD, with effect sizes and magnitude-based inference based on the difference between groups. ↓ and ↑ represents less than and greater than, respectively.

Stepwise discriminant analysis identified that a combination of seven physical characteristics would successfully discriminate between youth, academy and senior players (P < 0.001). The variables included with their corresponding Wilks Lambda were medicine ball throw (λ = 0.631), body mass (λ = 0.651), CMJ height (λ = 0.792), stature (λ = 0.872), prone Yo-Yo IR1 distance (λ = 0.931), change of direction time (λ = 0.942) and 20 m sprint time (λ = 0.976). These results suggest that some characteristics (i.e. medicine ball throw) were better able to discriminate across the three groups than others (i.e. 20 m sprint) indicating less overlap of the groups for each characteristic. Overall, seven characteristics contributed to the group classification. The squared canonical correlation was 0.560 meaning these seven performance measures combined accounted for 56.0% of the overall variance in the data set. Cross-validation classification based on the leave-one-out method indicated that the discriminant analysis corresponded with an accuracy of 72.2% overall, equating to 68.9% (162/235) of youth players, 79.0% (286/362) for academy players and 59.1% (78/132) for senior players.

Table 7. Position-specific anthropometric and physical characteristics.

		Winger/Fullback	Centres	Halves	Hooker	Prop	Back Row Forwards
Youth	Stature (cm)	174.6 ± 5.9	177.1 ± 5.2	172.9 ± 8.4	171.6 ± 7.2	178.4 ± 5.1	179.2 ± 6.2
	Body mass (kg)	69.3 ± 9.7	72.6 ± 7.5	66.4 ± 8.1	68.7 ± 10.5	85.3 ± 9.4	77.3 ± 8.3
	10 m sprint (s)	1.82 ± 0.09	1.81 ± 0.12	1.83 ± 0.13	1.85 ± 0.10	1.87 ± 0.11	1.82 ± 0.11
	20 m sprint (s)	3.12 ± 0.14	3.13 ± 0.15	3.19 ± 0.18	3.21 ± 0.17	3.22 ± 0.15	3.15 ± 0.16
	CMJ height (cm)	33.3 ± 6.7	34.1 ± 6.8	34.0 ± 6.4	34.6 ± 6.5	30.1 ± 7.3	33.7 ± 6.9
	Medicine ball throw (m)	6.4 ± 0.7	6.1 ± 1.2	5.9 ± 0.8	6.0 ± 0.8	6.8 ± 0.8	6.4 ± 0.6
	Change of direction (s)	19.78 ± 1.63	20.19 ± 0.96	20.36 ± 0.88	20.49 ± 1.10	20.81 ± 1.27	20.44 ± 1.04
	Prone Yo-Yo IR1 (m)	756 ± 248	742 ± 252	808 ± 232	777 ± 335	591 ± 249	702 ± 216
Academy	Stature (cm)	180.9 ± 6.5	181.4 ± 5.4	176.4 ± 5.0	173.8 ± 6.2	183.0 ± 6.1	183.0 ± 4.9
	Body mass (kg)	82.2 ± 9.5	85.3 ± 6.7	78.1 ± 6.8	78.1 ± 8.7	99.7 ± 11.7	90.9 ± 8.4
	10 m sprint (s)	1.80 ± 0.09	1.81 ± 0.09	1.83 ± 0.09	1.83 ± 0.09	1.91 ± 0.10	1.85 ± 0.12
	20 m sprint (s)	3.08 ± 0.15	3.10 ± 0.13	3.12 ± 0.14	3.11 ± 0.16	3.28 ± 0.15	3.16 ± 0.15
	CMJ height (cm)	41.9 ± 7.3	39.8 ± 5.8	38.3 ± 6.0	38.7 ± 5.3	34.2 ± 5.0	37.2 ± 5.3
	Medicine ball throw (m)	7.2 ± 0.9	7.3 ± 0.8	6.8 ± 0.8	6.8 ± 0.8	7.2 ± 0.8	7.3 ± 0.7
	Change of direction (s)	19.95 ± 1.27	20.11 ± 1.11	20.21 ± 1.06	20.08 ± 0.98	21.31 ± 1.46	20.54 ± 1.21
	Prone Yo-Yo IR1 (m)	773 ± 241	799 ± 226	871 ± 206	960 ± 256	615 ± 147	769 ± 215
Senior	Stature (cm)	180.4 ± 3.7	185.5 ± 5.8	178.3 ± 5.3	177.8 ± 4.1	187.4 ± 4.8	183.8 ± 4.7
	Body mass (kg)	90.3 ± 7.5	91.9 ± 8.1	90.2 ± 8.4	88.7 ± 6.3	107.7 ± 4.6	97.8 ± 8.9
	10 m sprint (s)	1.77 ± 0.08	1.83 ± 0.09	1.84 ± 0.07	1.82 ± 0.10	1.85 ± 0.10	1.82 ± 0.08
	20 m sprint (s)	3.01 ± 0.11	3.08 ± 0.10	3.14 ± 0.08	3.11 ± 0.11	3.13 ± 0.14	3.10 ± 0.12
	CMJ height (cm)	45.2 ± 4.8	43.0 ± 5.4	41.9 ± 4.0	44.3 ± 5.2	40.9 ± 4.5	41.0 ± 5.6
	Medicine ball throw (m)	8.0 ± 0.8	8.1 ± 0.6	7.8 ± 0.8	7.7 ± 0.7	8.5 ± 0.8	8.1 ± 0.9
	Change of direction (s)	19.09 ± 0.65	20.01 ± 1.06	19.65 ± 0.72	19.32 ± 0.67	20.15 ± 0.81	19.75 ± 0.70
	Prone Yo-Yo IR1 (m)	889 ± 224	885 ± 211	914 ± 255	1160 ± 275	834 ± 286	979 ± 307

Data are presented as mean ± SD. Youth - winger/fullback, centre, halves, hooker, prop and back row forwards; n = 48, 34, 38, 19, 33 and 63, respectively. Academy – winger/fullback, centre, halves, hooker, prop and back row forward; n = 60, 56, 46, 33, 70 and 97, respectively. Senior – winger/fullback, centre, halves, hooker, prop and back row forward; n = 26, 16, 19, 12, 26 and 33, respectively.

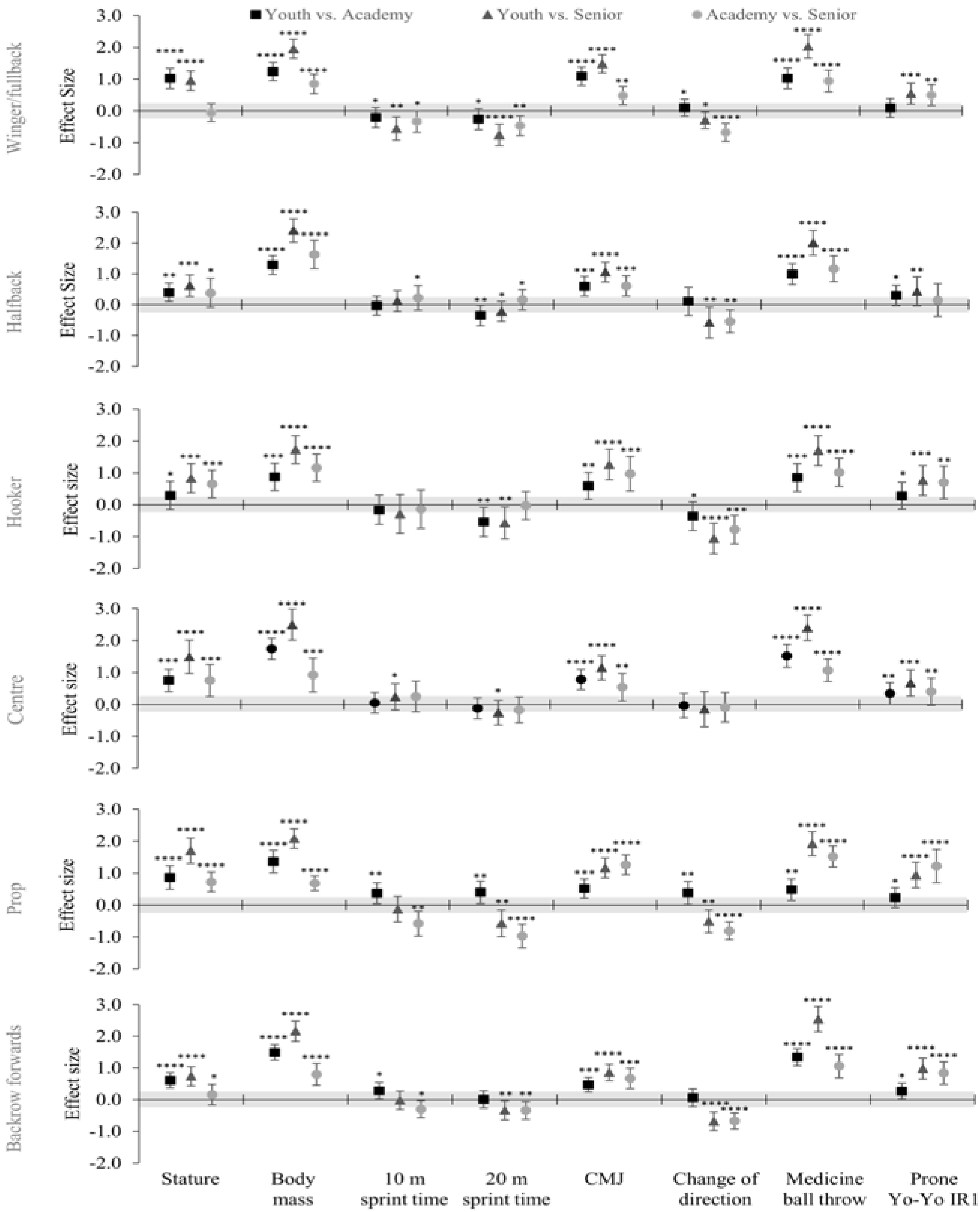

Figure 11. Within position comparisons for anthropometric and physical characteristics between youth, academy and senior players. Data expressed as an effect size ± 90% confidence limits. Magnitude-based inferences are included to demonstrate the certainly in difference between groups using the following qualitative descriptors: *possibly* *, likely **, very likely ***, most likely ****.

4.4. Discussion

This study assesses the ability of the RLAP battery to differentiate anthropometric and physical characteristics between youth, academy and senior rugby league players and explores how these tests discriminate between playing standards. Results revealed different anthropometric and physical profiles at senior compared to youth and academy standards, and that all but 10 m sprint time were able to discriminate between youth, academy and senior players. The RLAP battery is sensitive and can differentiate anthropometric and physical profiles within positional groups between youth, academy and senior rugby league players. Furthermore, the data presented in Table 6 and 7 can be used by practitioners as a normative data set that players can be compared against and informed decisions on the development needs of a player determined.

Anthropometric characteristics differentiated between playing standards reaffirming their importance in rugby league.[943,198,255] The difference observed between youth and academy players is expected and likely reflects maturation[255] as well as the greater training volume. Similarly, difference between youth/academy and senior players likely reflects the greater training volume. For example, the relative number of defensive tackles (forwards: 0.47 ± 0.23 *cf.* 0.34 ± 0.13 $n{\cdot}\text{min}^{-1}$; backs: 0.16 ± 0.11 *cf.* 0.13 ± 0.08 $n{\cdot}\text{min}^{-1}$ for senior and academy, respectively) and offensive carries (forwards: 0.20 ± 0.10 *cf.* 0.12 ± 0.06 $n{\cdot}\text{min}^{-1}$; backs: 0.15 ± 0.08 *cf.* 0.06 ± 0.04 $n{\cdot}\text{min}^{-1}$ for senior and academy, respectively)[71] likely explains the requirement of greater body mass in senior players. In agreement with Morehen et al.[198] for senior players but also for youth and academy, we observed large positional variation in stature and body mass. Differences in stature between youth and senior players ranged from moderate to large, whereas between academy and senior players, the magnitude was lower. Large differences in body mass were observed within positional groups between youth and academy players but was reduced to *moderate* when comparing academy to senior players. These results demonstrate that stature and body mass can discriminate between playing standards and should be included as part of a TID programme in rugby league.

Whilst smaller scale studies have inferred sprint speed differentiates between performance standards in rugby league,[94,124,2575] this study observed *trivial* differences in 10 m and 20 m sprint times between youth and academy players. This might be explained by the large increase in body mass[192] as players progress from youth to academy, meaning an impaired technical capacity[211] and players needing to overcome a greater inertia when sprinting from a stationary start. Despite senior players being heavier than both youth and academy, they possess similar or faster sprint times that suggests they could generate greater force and power during the sprints.[25] These observations reaffirm the importance of senior players possessing both high speed and high body mass in order to generate momentum into collisions,[218] though it should be noted that 10 m sprint times were excluded during the stepwise discriminate analysis. The within-position difference between playing standards revealed differences in 10 and 20 m sprint times between academy and senior wingers, halves, props and backrow forwards but not centres or hookers; albeit, few of these differences in sprint performance exceeded the required change. It is proposed that 10 m sprint times *per se* might not discriminate between youth and academy players regardless of playing position but that 20 m sprints times can discriminate between playing standards.

Senior players possessed most likely faster change of direction times compared to youth and academy players, with the mean difference exceeding the required change (0.76 cf. 0.67 s). However, similar to previous findings,[124] there was no meaningful difference in change of direction between youth and academy players. Again, the faster change of direction times for senior players is likely explained by increased exposure to specific training practices that enable greater muscle power contributing to change of direction ability.[69] Whilst only trivial differences existed between youth and academy mean change of direction times, a small difference was observed for hookers and props, though did not exceed the required change (Chapter 3). The change of direction test was able to differentiate senior wingers/fullbacks, hookers and back row forwards from academy and youth players. The similarity between youth and academy players could be explained by the trivial differences in 10 and 20 m sprint times as well as the potentially varied exposure to accelerating, decelerating and cutting mechanics during training. Discriminant analysis revealed that change of direction is a significant predictor of group membership and should be include in future testing batteries for the purpose of TID. However, when considering the between-group within-position data, caution is required as the magnitude of difference did not exceed the required change resulting in reduced confidence this difference is true and meaningful.

A *moderate* difference in CMJ was observed between youth and academy players, and academy and senior players, with the mean differences exceeding the required change (2.9 cm; Chapter 3). Similar observations for the medicine ball throw revealed *moderate* differences between youth and academy, and academy and senior players, all exceeding the required change of 0.7 m. Further, discriminant analysis revealed both CMJ and medicine ball throw as predictors of playing standard, though it is also important to recognise the within-position difference between groups. For example, differences in CMJ between youth and academy players ranged from small to moderate and were greater than the required change for all positions. Differences in CMJ between academy and senior players were in agreement with previous research,[12,13] ranging from small to large and were greater than 2.9 cm. Positional differences in the distance achieved during the medicine ball throw between youth and academy players ranged from small and large, exceeding 0.7 m for all positions except props. Positional differences in medicine ball throw between academy and senior players were more varied ranging from small to large. The large effect for CMJ and medicine ball throw between academy and senior props might suggest that this position becomes specialised as players' progress through to senior rugby and are required to develop power to a greater extent than other playing positions.

Small differences that did not exceed the required change (48 *cf.* 120 m) suggest the prone Yo-Yo IR1 was unable to differentiate between youth and academy players with a high degree of confidence. This finding suggests that use of this characteristic to determine the progression of an athlete from youth to academy might be limited and that increasing body mass and other characteristics without impairing prone Yo-Yo IR 1 performance should be the focus. However, when combined with the six additional variables, the stepwise discriminant analysis revealed the prone Yo-Yo IR1 was a significant predictor of playing standard. The large increase in body mass (ES = 1.21) from youth to academy probably impacts negatively on the older player's ability to get up from the prone position and perform intermittent shuttle running.[63] While academy coaches might focus on increasing body mass to aid running momentum and impact forces during the collision[264] as players progress from youth rugby, they should be mindful of the detrimental trade-off on rugby-specific high intensity running. In contrast, moderate differences exceeding 120 m were observed between younger (i.e. youth and academy) and senior players. Whilst senior players also possess greater body mass, they seemingly tolerate this better during the prone Yo-Yo IR1 probably because of the smaller increases in body mass from academy to senior rugby (ES = 0.70) and greater emphasis on specific high intensity training. Collectively, the ability to get up from the prone position, accelerate and perform repeated intermittent running, while also maintaining a high body mass, is important for elite rugby league players. Positional differences for the prone Yo-Yo IR1 between youth and academy halves were trivial whereas all other positional differences were small. A trivial difference was also observed when comparing academy and senior halves; small for wingers/fullbacks and centres; moderate for hookers and back row forwards; and large for props. These observations might reflect differences in position-specific training as players progress from academy to senior rugby, and that based on the discriminant analysis, should be incorporated into future assessments of a player's high-intensity intermittent running ability.

Discriminant analysis determined that seven of the eight performance measures included in the battery (i.e. stature, body mass, 20 m sprint times, CMJ height, change of direction time, medicine ball throw distance and prone Yo-Yo IR1 distance) discriminated between youth, academy and senior players. These accounted for 56% of the variance between youth, academy and senior players, with the remaining 44% accounted for by other variables associated with sporting performance (e.g. technical, tactical, social and psychological skills). Overall, the analysis possessed a predictive accuracy of 72.2%, which equated to 68.9% for youth players, 79.0% for academy players and 59.1% for senior players. These results suggest that a combination of seven performance measures were able to place youth and academy players to a greater degree of accuracy compared to senior players where a large (41.1%) proportion of players were incorrectly placed into the academy group. Furthermore, a third (31.1%) of youth players were incorrectly identified as academy players while 12.4% and 8.6% of academy players were incorrectly placed within the youth and senior groups, respectively. Results indicated a degree of overlap in the physical characteristics between youth and academy, and senior and academy players, suggesting that additional factors beyond physical characteristics also play an important role in talent progression and identification. Nonetheless, the high degree of predictive accuracy suggests that practitioners can use RLAP to discriminate between performance standards in rugby league.

Whilst this study provides data on elite rugby league players across multiple clubs, inherent limitations exist. All data was collected at the start of the pre-season period and might not reflect the 'optimal' anthropometric and physical characteristics of players.[258] The author also acknowledges no measure of muscle strength was included within the battery. However, the construct validity of a portable mid-thigh pull dynamometer for discriminating between youth and senior rugby league players (Appendix 12) has been validated and could be included in the RLAP battery.

4.5. Practical applications and conclusion

The RLAP battery is able to differentiate between playing standards and, excluding 10 m sprint time, possesses discriminant validity. The battery of tests can, for the most part, be used to differentiate within playing positions between youth, academy and senior standards. Finally, the data represents normative data for UK-based youth, academy and senior rugby league players. As such, practitioners in rugby league can use this battery and the data presented to monitor players and support the decision-making process concerning a player's development or progression through performance standards in rugby league.

This study demonstrates the discriminant validity of the RLAP battery for assessing anthropometric and physical characteristics between youth, academy and senior rugby league players. The results revealed that senior players possessed superior anthropometric and physical characteristics compared to youth and academy players, with fewer clear differences between youth and academy players. Furthermore, playing position influenced the magnitude of difference between performance standards and should be considered when assessing the anthropometric and physical characteristics to inform talent identification and monitor player development in rugby league.

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Chapter 5

The concurrent validity of the prone Yo-Yo Intermittent Recovery Test (Level 1) for assessing match-related running performance

The systematic review in Chapter 2 highlighted that, despite a plethora of well-established tests, there existed no sport-specific measure of prolonged high-intensity intermittent running for rugby league players. That is, a protocol that assessed the necessary physiological components while incorporating movement characteristics typical of those performed by rugby league players. The original battery proposed by the RFL at the start of this project included a modified Yo-Yo IR1 that was subsequently shown in the previous two chapters to be both reliable (Chapter 3) and to discriminate between playing standards (Chapter 4) of professional rugby league players. To further understand the suitability of the prone Yo-Yo IR test to the RLAP battery and if the modification to the original protocol had enhanced the newly proposed test's specificity, Chapter 5 sought to establish the concurrent validity of the test when compared to simulated match-play and if the strength of association improved when compared to the running-based Yo-Yo IR1.

Dobbin, N., Highton, J., Moss, S. L., Hunwicks, R., & Twist, C. (2018). Concurrent validity of a rugby-specific yo-yo intermittent recovery test (level 1) for assessing match-related running performance. *Journal of Strength and Conditioning Research,* doi: 10.1519/JSC.0000000000002621.

5.1. Introduction

Objective evaluation of rugby league players' physical characteristics enables practitioners to monitor individual development and assess the effectiveness of training programmes.[98] The assessment of high-intensity intermittent running (HIIR) capacity, referring to one's ability to repeatedly perform intense exercise and recover,[180] is of interest given its contribution to repeated high-intensity efforts (i.e. number of tackles) and the team's scoring and defensive capabilities.[91] High-intensity intermittent running is also reported to influence post-match recovery,[168] injury risk,[90] and is a key indicator for talent identification programmes.[98]

Field-based tests such as the Yo-Yo IR1[180] and $30\text{-}15_{IFT}$[31] are often used to assess HIIR capacity in rugby league players as reported in the Chapter 2. Performance in these tests is defined as the total distance covered or peak running speed attained, both of which show strong associations with maximal oxygen uptake ($\dot{V}O_{2max}$).[90,220] However, as players with a similar $\dot{V}O_{2max}$ can achieve a peak distance or velocity during these tests that differs by ~1000 m[180] or 4 $km \cdot h^{-1}$,[31] it is clear HIIR has several physiological determinants. Indeed, Scott et al.[220] recently demonstrated that $\dot{V}O_{2max}$ determined by a multistage fitness test, mean speed during a 2000 m time trial and peak velocity over 40 m accounted for 70.2% of variance in $30\text{-}15_{IFT}$ performance in rugby league players.

Notwithstanding the multiple physiological contributors to performance during the Yo-Yo IR1 and $30\text{-}15_{IFT}$, high-intensity intermittent running, as determined by the Yo-Yo IR1, differentiates between playing standard, fatigue responses and match activity profiles in junior male rugby league players.[168] Those classified as high fitness covered greater distance, high-speed running, number of collisions and number of repeated high-intensity efforts.[168] Despite this, Gabbett and Seibold[92] reported no significant relationship between Yo-Yo IR1 distance and measures of match performance, including total (r = 0.05), low-speed (r = 0.04) and high-speed (r = 0.09) distance as well as total collisions (r = -0.70) and repeated high-intensity efforts (r = -0.23) in male semi-professional players. As intermittent running during rugby match-play is frequently interspersed with collisions, which increases the physiological strain imposed,[204] it is likely that this action alters the relationship between an entirely running-based intermittent field test and match-play as well as influencing the physiological determinants being evaluated.[10] As such, limitations with the concurrent validity of the Yo-Yo IR1 and its association to rugby league match performance have been reported and suggest a rugby-specific measure of HIIR is warranted.[10]

Gabbett and Seibold[92] suggest the need for a rugby-specific measure of HIIR that includes both repeated running efforts and collisions that could be included within current training practices.[172] However, this could be difficult to standardise, assess large groups of players at once and could increase injury risk.[236,261] An alternative approach that carries minimal injury risk is adopting certain components of physical contact but not the contact *per se*. For example, participants dropping to the ground in a prone position before returning to run imposed a greater physiological demand on participants during simulated match-play.[236] Therefore, the inclusion of this action during a test of HIIR might be worthwhile to increase the load imposed and more closely reflect that of match-play.[236,261] However, before such a test can be used, it is essential to determine its validity against measures of rugby match performance.

The relationship between players' physical characteristics and match-related movements has been studied during actual matches.[92] However, in determining the concurrent validity of a test for measuring rugby-specific HIIR, it is necessary to consider contextual, positional and match-to-match variability in movement characteristics during rugby league match-play.[178] Simulated match-play that controls for this variability might provide a useful tool for assessing the concurrent validity of a test. With this in mind, the purpose of this study was to establish the concurrent validity of a rugby-specific version of the Yo-Yo IR1 (prone Yo-Yo IR1) and Yo-Yo IR1 against the change in internal, external and perceptual loads between two bouts of simulated match-play.

5.3. Methods

5.2.1. Participants

With institutional ethics approval from the University of Chester, 36 academy (*n* = 20) and University-standard (*n* = 16) rugby league players (mean ± SD; age 18.5 ± 1.8 years; stature 181.4 ± 7.6 cm; body mass 83.5 ± 9.8 kg) completed the prone Yo-Yo IR1 and RLMSP-i, with a sub-sample (*n* = 16; *age* 20.2 ± 1.1 years; stature 182.9 ± 6.7 cm; body mass 82.2 ± 8.3 kg) also completing the Yo-Yo IR1. All participants provided written informed consent and completed a pre-test health questionnaire before starting the study. Parental assent was provided for all participants < 18 years old. Participants were free from injury at the start of the study, which was confirmed by the participants and the club's medical team.

5.2.2. Study design

The repeated measures design required all participants to perform the prone Yo-Yo IR1 and the sub-sample to complete the Yo-Yo IR1 in a randomised order. One to two weeks after the prone Yo-Yo IR1, all participants completed the Rugby League Match Simulation Protocol for interchange players (RLMSP-i).[261] All trials were completed after a rest day, with participants having done no club- or leisure-based activity for at least 24 hours beforehand. Trials were performed on an outdoor synthetic grass pitch (3G all-weather surface) at the same time of day (± 2 hours). Mean temperature and humidity were 11.8 ± 3.4°C and 72.4 ± 1.9%, respectively. Participants were asked to maintain a similar diet for each testing day, refrain from caffeine 12 hours before, attend well-hydrated and wear the same clothing and footwear (studded boots) for each visit.

5.2.3. Procedures

Standard and modified Yo-Yo Intermittent Recovery Test Level 1

Participants undertook a standardised warm-up before completing as many 40 m (2 x 20 m) shuttles as possible with a 10 s active recovery (walking) between shuttles as directed by an audio signal.[180] Running speed for the test commenced at 10 $km \cdot h^{-1}$ and increased 0.5 $km \cdot h^{-1}$ approximately every 60 s until the participants could no longer maintain the required running speed. During the standard test, participants started in a two-point stance, whilst during the prone Yo-Yo IR1 participants were required to start each shuttle in a prone position with their head behind the start line, legs straight and chest in contact with the ground. Total distance was recorded after the second failed attempt to meet the start/finish line in the allocated time for both tests. Both the Yo-Yo IR1 (CV = 4.9%)[180] and prone Yo-Yo IR1 (CV = 9.9%) (Chapter 3) are reported as reliable.

Rugby League Movement Simulation for Interchange Players

Participants were paired based on stature and body mass before repeating the standardised warm-up. The RLMSP-i consisted of two 23-minute bouts of activity interspersed with a 20-minute passive recovery period to replicate the mean match demands of elite interchange rugby league players.[261] Each bout consisted of 12 repeated cycles of activity and included two parts; ball in-play and ball out-of-play. Participants were instructed to perform each sprint 'maximally' to reproduce the demands of match-play. At contact, participants were instructed to flex the hips, knees and ankles while contacting a tackle shield held by their opponent (Gilbert Rugby, East Sussex, England) using their preferred shoulder. Three seconds after contact, the participants dropped into a prone position before returning to a standing position and waiting for the next instruction.

External response

Movement characteristics were recorded using a 10 Hz microtechnology device (Optimeye S5, Catapult Innovations, Melbourne, Australia) fitted into a custom-made vest positioned between the participant's scapulae. The mean ± SD number of satellites and horizontal dilution of precision (HDOP) was 13.8 ± 1.1 and 0.7 ± 0.1, respectively. Total distance was recorded and categorised into low (< 14.0 $km \cdot h^{-1}$) and high (> 14.1 $km \cdot h^{-1}$) intensities. Mean speed was calculated and peak speeds ($km \cdot h^{-1}$) of sprint A and B were measured; where sprint A and B represent the first and second 20.5 m sprint during each cycle of the simulation, respectively. Peak speed was determined as the peak absolute speed reached during the whole simulation. The fatigue index was calculated using all 48 sprint performances and the following equation: *Fatigue = 100 * EXP*$^{(slope/100)}$*-100*, where the slope is calculated using the line of best fit for: 100 x natural logarithm of sprint data) x (number of sprint -1).[130] The built-in 100 Hz triaxial accelerometer, gyroscope and magnetometer were used to determine high metabolic power (HMP) (> 20 $W \cdot kg^{-1}$). In-house analysis has revealed that the coefficient of variation for relative distance, low-speed running, high-speed running and peak speed were between 1.3-1.9%, 2.2-3.3%, 8.0-14.4% and 3.7-9.6%, respectively for bout 1 and 2 of the RLMSP-i.[205]

Internal and perceptual responses

A heart rate (HR) monitor (Polar Electro Oy, Kempele, Finland) was wirelessly paired to the microtechnology device and analysed using custom software (Sprint, Version 5.1, Catapult Sports, VIC, Australia). Heart rate data were analysed as a percentage of the participant's peak HR recorded during the simulation (%HR_{peak}). Rating of perceived exertion (RPE) was recorded using the Borg 6-20 scale[27] during the simulation with a CV of 13.7 and 11.2% for bout 1 and 2, respectively. Blood lactate concentration ($[La]_b$ Arkray, Lactate Pro, Arkay, Kyoto, Japan; CV = 8.2%) was also measured from a fingertip capillary sample before the warm up and immediately after each bout.

5.2.4. Statistical analysis

Data are presented as mean ± SD. To evaluate any changes between RLMSP-i bouts, magnitude based-inferences were used with the following 90% confidence limits: <0.5% most unlikely, 0.5-5% very unlikely, 5-25% unlikely, 25-75% possibly, 75-95%

likely, 95-99.5 very likely, >99.5 most likely. Magnitude of the observed change was assessed using the following thresholds: trivial <0.2, small 0.2 - 0.6, moderate 0.6 - 1.2, large 1.2 - 2.0, and very large >2.0.[153] To assess associations between a range of internal and external measures and distance covered during the prone Yo-Yo IR1, Pearson's correlation coefficient (*r*) with the following criteria were adopted to interpret the magnitude of the correlation between variables: <0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect,[151] and was based on the change between bouts for relative total, low-speed and high-speed distance, mean speed and HMP, and raw values for fatigue index, the percentage change between sprints A and B, $\%HR_{peak}$, RPE and $[La]_b$. If the confidence limits overlapped small positive and negative values when comparing the between-bout responses the effect was considered unclear. Statistical analysis was conducted using a predesigned spreadsheet for comparing means[148] and assessing correlations.[152]

5.3. Results

For the RLMSP-i, total low-speed and high-speed relative distances as well as mean speed were *most likely* lower during bout 2 when compared to bout 1. Time spent at HMP was *most likely* lower during bout 2 compared to bout 1. Differences for peak speed and the magnitude of change between sprint A and B (the difference between the first and second 20.5 m sprint during each cycle) were *unclear,* whereas a *possibly* higher fatigue index occurred in bout 2. RPE and $\%HR_{peak}$ were *very likely* and *likely* higher at the end of bout 2 compared to bout 1, yet no clear difference was observed for $[La]_b$. All data are shown in Table 8.

Table 8. Internal and external responses during the RLMSP-i. Data are effect size ± 90% CI and qualitative descriptors for Bout 1 vs. Bout 2 comparisons.

	Bout 1	Bout 2	Whole Simulation	Between bout comparisons
Relative distance ($m \cdot min^{-1}$)	100 ± 5	98 ± 5	99 ± 5	-2.1%, -0.44 ± 0.09; *Most likely*
Relative low-intensity ($m \cdot min^{-1}$)	76 ± 4	74 ± 5	75 ± 4	-4.0%, -0.81 ± 0.27; *Most likely*
Relative high-intensity ($m \cdot min^{-1}$)	24 ± 2	23 ± 3	24 ± 2	-7.3%, -0.77 ± 0.25; *Most likely*
Mean speed ($km \cdot h^{-1}$)	5.94 ± 0.29	5.82 ± 0.27	5.88 ± 0.28	-2.0%, -0.41 ± 0.06; *Most likely*
Time > HMP (min)	2.13 ± 0.26	1.88 ± 0.33	4.00 ± 0.54	-8.9%, -0.93 ± 0.40; *Most likely*
Mean peak speed ($km \cdot h^{-1}$)	25.2 ± 2.0	25.2 ± 2.3	25.2 ± 2.1	-0.4%, -0.05 ± 0.27; *Unclear*
Fatigue Index (%)	-11.1 ± 7.4	-12.6 ± 8.6	-8.5 ± 54.7	21.7%, 0.15 ± 0.31; *Possibly*
∆ between sprint A and B (%)	-5.0 ± 2.2	-5.1 ± 2.1	-5.7 ± 2.1	4.9%, 0.10 ± 0.33; *Unclear*
HR_{peak} (%)	86.9 ± 6.7	87.6 ± 7.4	86.2 ± 6.4	0.5%, 0.07 ± 0.19; *Likely*
RPE (AU)	12.7 ± 2.3	13.8 ± 2.3	13.2 ± 2.4	12.1%, 0.94 ± 0.48; *Very likely*
$[La]_b$ (mmol)	3.21 ± 1.63	3.47 ± 1.85	3.34 ± 1.74	3.3%, 0.06 ± 0.51; *Unclear*

Low-intensity running: < 14 $km \cdot h^{-1}$. High-intensity running: > 14 $km \cdot h^{-1}$. HMP = high metabolic power (> 20 $W \cdot kg^{-1}$). ∆ between sprint A and B (%) = the difference between the first and second 20.5 m sprint with each cycle.

There was a large negative correlation between total distance during both Yo-Yo IR1 tests and the percentage change in relative distance between bouts, but only trivial correlations for low- and high-speed distance. There was a moderate and large correlation between distance covered in the Yo-Yo IR1 and prone Yo-Yo IR1 with the percentage change in mean speed during the RLMSP-i. A small and moderate positive correlation was observed between distance covered in the Yo-Yo IR1 and prone Yo-Yo IR1 with percentage change in time spent at HMP, respectively. A very large positive correlation was observed between distance covered during the prone Yo-Yo IR1 and fatigue index and percentage difference between sprints A and B, with large correlations observed for the Yo-Yo IR1. All data are shown in Figure 12.

There was a large and moderate negative correlation between prone Yo-Yo IR1 and Yo-Yo IR1 with $\%HR_{peak}$ during the RLMSP-i. Rating of perceived exertion at the end of the both halves was moderately and largely correlated with prone Yo-Yo IR1 distance (Figure 2) whereas small and moderate correlations were observed with the Yo-Yo IR1. Trivial correlations were observed between $[La]_b$ and prone Yo-Yo IR1 distance (Figure 13), but was moderately correlated with Yo-Yo IR1 distance.

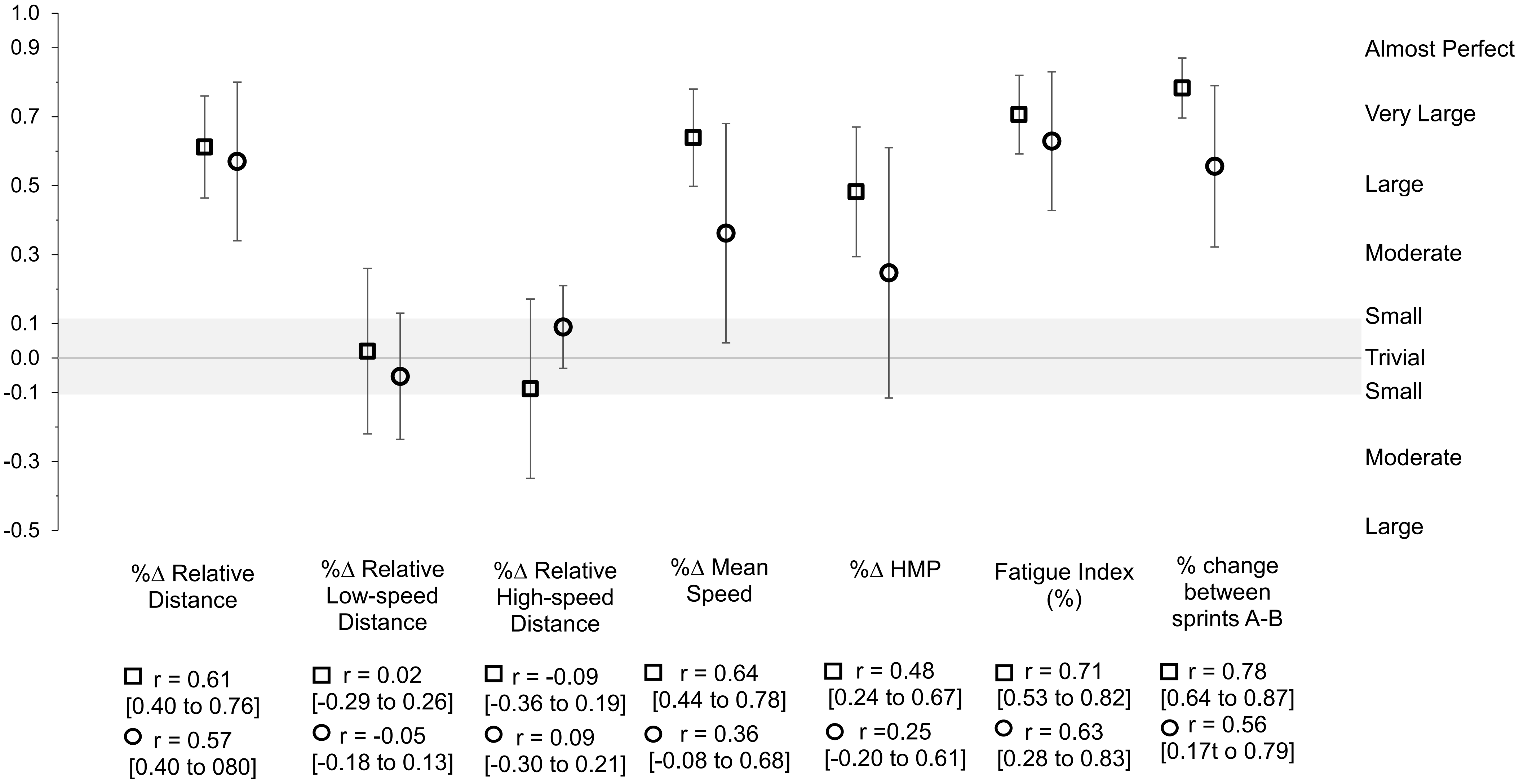

Figure 12. Relationship between Prone Yo-Yo IRT (squares) and Yo-Yo IR1 (circles) distance with the changes in the external responses between bouts during the RLMSP-i. Correlation coefficient (*r*) is presented with 90% confidence intervals. CI – confidence intervals; HMP = high metabolic power; RLMSP-i = rugby league match simulation protocol for interchange players; Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1

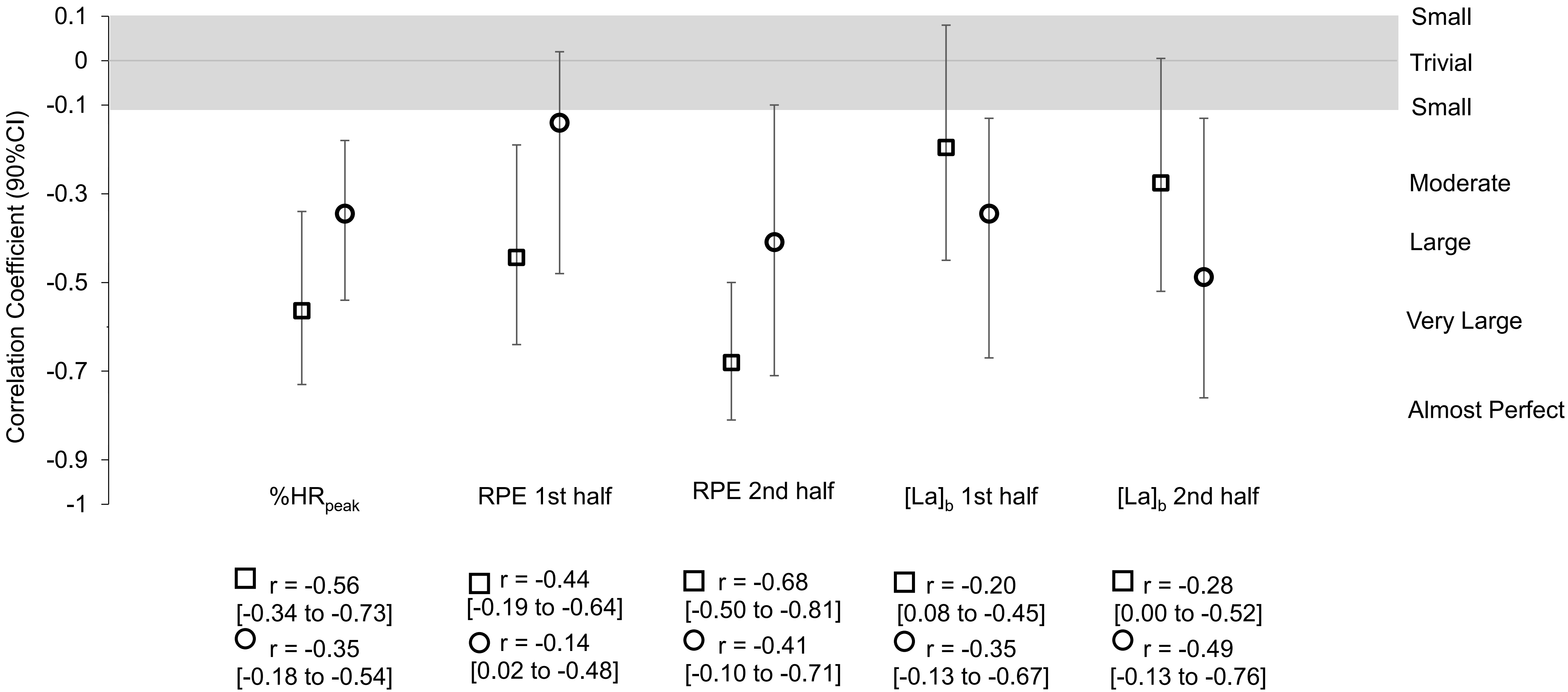

Figure 13. Relationship between Prone Yo-Yo IR1 (squares) and Yo-Yo IR1 (circles) distance with the changes in the internal and perceptual responses during the RLMSP-i. Correlation coefficient (*r*) are presented with 90% confidence intervals. CI – confidence intervals; HMP = high metabolic power; RLMSP-I = rugby league match simulation protocol for interchange players; Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1.

5.4. Discussion

This study investigated the concurrent validity of a prone Yo-Yo IR1 for the assessment of rugby-specific HIIR. The findings confirm that prone Yo-Yo IR1 distance was associated with RLMSP-i running performance, most notably the ability to maintain peak and repeated sprint speeds and a lower internal load during the RLMSP-i. Furthermore, the prone Yo-Yo IR1 was more strongly associated with some common measures of match loads than the Yo-Yo IR1 supporting its inclusion in the RLAP battery. Accordingly, the prone Yo-Yo IR1 presents an appropriate measure of rugby-specific HIIR that partly explains the changes in internal and external load during simulated match-play.

The internal (86.2 ± 6.4 *cf.* 84.1 ± 8.2 $\%HR_{peak}$) and external (99 ± 5 *cf.* 95 ± 7 $m \cdot min^{-1}$) responses to the RLMSP-i were consistent with those observed for interchange players during match-play.[263] The reduction in time at HMP between bouts, when expressed relative to time, was also comparable to rugby league match-play.[178] Therefore, notwithstanding the challenges associated with replicating the true demands of a match,[28] these data confirm that the RLMSP-i can be used to adequately replicate the internal and external response.

These results indicated a large correlation between prone Yo-Yo IR1 and Yo-Yo IR1 distance and a player's change in relative distance during the RLMSP-i. Combined with the large and moderate relationship with change in mean speed between bouts of RLMSP-i, these results suggest that performance during both Yo-Yo IR1 tests can influence the running intensity that an individual sustains during simulated match-play as well as their ability to resist fatigue and recover between ball-in-play periods. As exercise time and total distance remained constant for all participants during the RLMSP-i, any changes in relative distance and mean speed between playing bouts are likely attributed to a progressive reduction in the sprint and sprint to contact speeds associated with peripheral[28] and central fatigue.[199] Changes in sprint to contact speed might have resulted in some variability in displacement during the collision (i.e. greater fatigue resulted in participants not pushing the opponent back as far in the contact), thus potentially explaining the relationship between both Yo-Yo tests and relative distance.

Interestingly, only trivial relationships were observed between the Yo-Yo IR1 and prone Yo-Yo IR1 distance and the percentage change in low- or high-speed distance. The large between-participant variation resulted in a lack of systematic change between bouts. For example, for those players who achieved a prone Yo-Yo IR 1 distance of 800 m, the percentage change for low- and high-intensity running between bouts were between 0.1 to -4.4% and 0.4 to -10.3%, respectively. Moreover, the use of total, low- and high-speed distance might not necessarily be indicative of the load on players as the metabolic and mechanical costs of sport-specific movements are not represented.[178]

The author identified a moderate relationship between prone Yo-Yo IR1 distance and the change in time spent at HMP (> 20 $W \cdot kg^{-1}$) between bouts, suggesting those players who have greater rugby-specific HIIR can sustain combined accelerated and high-speed running during the RLMSP-i. In contrast, only a small relationship was observed between time spent at HMP and total distance during the Yo-Yo IR1, suggesting the inclusion of a metabolically demanding action during the prone Yo-Yo strengthens its relationship with simulated match-play. While HMP underestimates the metabolic costs associated with the collision,[143] this metric does provide some evidence that rugby-specific HIIR is positively related to an individual's ability to perform and sustain metabolically demanding actions during a simulated match. Accordingly, the prone Yo-Yo IR1 might provide further insight into a player's ability to maintain fundamental movements across playing bouts, including accelerating, decelerating, changing direction and getting up-and-down quickly.

A large correlation between Yo-Yo IR1 distance and fatigue index during the RLMSP-i was observed and this relationship was strengthened when using the prone Yo-Yo IR1 distance. These findings suggest that players who demonstrate greater HIIR and rugby-specific HIIR were better able to maintain sprint speed during the RLMSP-i. Whilst repeated sprint ability was not measured in this study, the very large correlation observed between prone Yo-Yo IR1 distance and the percentage difference between sprint A and B within each cycle of the RLMSP-i, agrees with previous research in soccer where a significant relationship ($r = -0.573$) was observed between the distance covered during the Yo-Yo IR1 and mean speed during 7 x 35 m repeated sprints.[159] Therefore, it is proposed that those who scored higher on the prone Yo-Yo IR1 were able use a greater proportion (~40%) of their aerobic capacity for the re-phosphorylation of adenosine triphosphate, reducing their reliance on anaerobic metabolism and associated fatigue.[127] The relationship between the percentage difference for sprint A and B and distance was poorer for the Yo-Yo IR1 in comparison to the prone version. This suggests the increased emphasis on getting up and accelerating is more closely related to demands of repeated sprinting during the RLMSP-i.

A moderate and large negative correlation between Yo-Yo IR1 and prone Yo-Yo IR1 distance with $\%HR_{peak}$ during the RLMSP-i reaffirms the work of Krustrup et al.[180] who observed an inverse relationship between distance covered and $\%HR_{peak}$ during the Yo-Yo IR1. A moderate and large relationship was also observed between prone Yo-Yo IR1 distance and RPE during bouts 1 and 2, respectively. However, this relationship was weakened when total distance from the Yo-Yo IR1 was used. Collectively, these data indicate that HIIR is related to the internal and perceptual loads during the RLMSP-i, but that this relationship was stronger for the prone Yo-Yo IR1. As such, greater rugby-specific HIIR could allow players to perform the RLMSP-i with a lower internal load, possibly owing to a greater physiological capacity and improved recovery between ball-in-play periods. However, only small to moderate correlations were reported between prone Yo-Yo IR1 and Yo-Yo IR1 distance, and $[La]_{b,}$ which might be explained by poor reliability of [La] during the RLMSP-i,[261] or the time-frame of up to five minutes required for completion of sampling.

Despite similar movement demands, the reduction in external load between bouts (~5%) was smaller than that observed during match-play (~15%),[263] which is likely due to the difficulties in replicating the physical contact in the simulation.[236] However, the use of simulated match-play strongly suggests that prone Yo-Yo IR1 distance is related to commonly used measures of load during activities that closely reflect match-play without interference from match-related factors. Further research might explore the validity of the prone Yo-Yo IR1 against performance measures during match-play using a multilevel mixed model approach that controls for other confounding variables and explores additional physical qualities. It is also important to note that the correlations observed in this study are based on academy and university-standard players who demonstrate a reduced prone Yo-Yo IR1 (Chapter 4) compared to senior elite players. As such, future research might explore the relationship between prone Yo-Yo IR1 distance and measures of match performance in elite players. Finally, whilst this study provides evidence that rugby-specific HIIR is related to the internal, external and perceptual measures of load, its influence on a player's ability to maintain skill performance is unknown.

This study highlights that rugby-specific HIIR is related to the internal, external and perceptual responses during simulated match-play. A greater prone Yo-Yo distance resulted in better maintenance of running speed, high metabolically demanding actions and sprint speed between two bouts of the RLMSP-i. Further, those individuals who achieved the greatest distance during the prone Yo-Yo IR1 had a reduced $\%HR_{peak}$ and RPE. As such, the prone Yo-Yo IR1 might be used to evaluate several physical characteristics important for success in rugby league matches.

5.6. Conclusion and practical applications

The prone Yo-Yo IR1 is related to a player's internal, external and perceptual responses during the RLMSP-i and can be used to assess rugby-specific HIIR. These results indicate that the prone Yo-Yo IR1 is more strongly related to several commonly used measures of training or match load in rugby league compared to the Yo-Yo IR1 and justifies this being included in the RLAP battery. Given the relationship between distance covered during the prone Yo-Yo IR1 and measure of internal and external load during RLMSP-i, practitioners should focus on developing rugby-specific HIIR during training in an attempt to minimise the anticipated reduction in intensity between bouts of activity in rugby league match-play.

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Chapter 6

An examination of a modified Yo-Yo test to measure intermittent running performance in rugby players

The results of Chapters 2, 3 and 4 highlighted that a rugby-specific Yo-Yo IR1 was reliable, discriminated between playing standard and possessed concurrent validity with simulated match-play, respectively. However, an early observation was the lower total distance covered when comparing the result of Chapter 2 and 3 that used the modified Yo-Yo IR1 to those in the literature using the Yo-Yo IR1 (Chapter 1). It was hypothesised that the inclusion of rugby-specific actions, which improves its association with simulated match-play (Chapter 5), increased the demands of the test and results in early cessation. Given the paucity of research on this test, there was a need to understand the physiological responses to this test in order to determine if, and to what extent, if offered new insight into an athlete ability beyond the traditional Yo-Yo IR1 test. Hence, Chapter 6 sought to compare the internal, external and perceptual responses to the rugby-specific Yo-Yo IR1 and Yo-Yo IR1.

Dobbin, N., Moss, S. L., Highton, J., & Twist, C. (2018). An examination of a modified yo-yo test to measure intermittent running performance in rugby players. *European Journal of Sport Science, 18*(8), 1068-1076.

6.1. Introduction

High-intensity efforts, involving repeated running and collisions, are important for success in rugby and are strongly associated with ‘critical’ moments (e.g. scoring/conceding a try) and match outcomes.[91,179] For example, players perform up to 25 high-intensity efforts during rugby league match-play with ~56% of these preceding a try.[91] Players are engaged in metabolically demanding actions including collisions, followed by getting up from the floor, acceleration/deceleration and changes of direction.[5,91,98,178] These actions, when combined with running, impose a greater physiological load on an individual when compared to running alone.[204,208] As such, the ability to monitor an athlete using a test that employs match-specific movements would be beneficial to understand performance capability in collision sport athletes.

The Yo-Yo IR1[5] and 30-15$_{IFT}$[219] have been used to assess the intermittent running ability of rugby players. However, as players must get up from the floor after a collision before moving to the next position ~40 times during match-play (i.e. joining the attack or retreating into the defensive line);[129] incorporating some of these actions within traditional running-based tests might provide a better reflection of the metabolic and physiological responses typically observed during match-play. Whilst the inclusion of a collision during the test could increase the risk of injury, incorporating repeated up-and-downs as per Studies 1 to 3, might provide further insight into a player’s ability to perform this fundamental action, accelerate/decelerate and change direction alongside high-intensity running. The addition of these sport-specific actions has been used in simulations of rugby league match-play,[236] and Chapter 5 revealed associations (r = 0.48-0.78) between distance covered during the prone Yo-Yo IR1 and measures of external (e.g. relative distance, HMP and repeated sprinting) and internal (e.g. HR, RPE) responses during simulated match-play. Despite the potential for this modified test, the physiological and performance responses to intermittent running tests with and without repeated up and down actions remain unknown. In particular, repeatedly getting up and down is likely to alter running performance when trying to maintain a given speed, while heavier players might be disadvantaged.[63] Furthermore, it seems prudent to investigate if, and to what extent, a modified test assesses distinct physical characteristics; thus, differentiating it from the original test and providing practitioners with further insight into an athlete's performance capabilities.

This study proposed to: 1) investigate the internal, external and perceptual responses to the Yo-Yo IR1 test; whereby participants start each shuttle in either a prone (prone Yo-Yo IR1) or standing position (Yo-Yo IR1), and 2) determine the relationship between the Yo-Yo IR1 and prone Yo-Yo IR1, and body mass. It was hypothesized that the up-and-down actions would elicit a greater cardiovascular, metabolic and perceptual load due to the greater involvement of upper-body musculature and greater emphasis on accelerated running, both of which would negatively affect total distance covered. Furthermore, we propose that a strong relationship between Yo-Yo IR1 tests would be observed but that the modified Yo-Yo IR1 would provide greater insight on the participant's ability to perform high metabolically demanding actions, thus justifying its inclusion in the RLAP battery beyond the traditional test. It was also hypothesized that there would be a negative association between body mass and distance covered in both tests, with a stronger association observed for the prone Yo-Yo IR1.

6.2. Methods

6.2.1 Participants

With institutional ethics approval and informed consent, 17 male university-standard rugby players (age = 20.4 ± 1.2 y, stature = 182.6 ± 5.7 cm, body mass = 83.7 ± 9.5 kg) volunteered to participate in the study. Data were collected one month before the end of the season, with all participants actively participating in a minimum of two rugby-specific training sessions and one match per week.

6.2.2 Study design

Using a repeated measures design, participants were required to attend the laboratory on two separate occasions at the same time of day (± 2 hours) separated by 2-5 days. During the initial visit, participants completed measures of stature and body mass before being randomly allocated to complete the Yo-Yo IR1 or prone Yo-Yo IR1. During the second visit, participants completed the remaining condition. Mean and standard deviation ambient temperature and humidity during the two trials was 16.5 ± 2.3°C and 59.0 ± 5.0%, respectively. During both trials, measurements of expired air, $[La]_b$, RPE, HR and movement demands were recorded. Participants were asked to avoid exercise and replicate their diet in the 24 h before each visit.

6.2.3 Procedures

Yo-Yo Intermittent Recovery Test Level 1

The Yo-Yo IR1 was performed as previously described[180] on an outdoor synthetic grass pitch (3G all-weather surface). Briefly, the Yo-Yo IR1 consisted of 2 x 20 m shuttles followed by a 10 s active recovery (5 m deceleration, 180° change of direction and walk to the line), with all participants completing two practice shuttles at a low-speed before the test started. The test consisted of 4 shuttles at 10-13 km·h^{-1} (0-160 m), 3 shuttles at 13.5 km·h^{-1} (200-280 m) and 4 shuttles at 14.0 km·h^{-1} (320-440 m), thereafter the speed increased 0.5 km·h^{-1} every 8 shuttles (i.e. 760, 1080, 1400 m, etc.). Running speed was governed by an audio signal and participants were instructed to complete as many 40 m shuttles as possible. The test was terminated when the participant failed to reach the start line before the audio signal on a second occasion and the total distance covered recorded (no. shuttles x 40 m). During the prone Yo-Yo IR1, participants completed the same test described above but were required to start each shuttle from a prone position that was adopted at the end of each 10 s recovery phase with their head behind the start line, legs straight and chest in contact with the ground. All trials were completed individually to remove any external influences and the researcher provided consistent encouragement during the testing procedures. The coefficient of variation (9.9%) and intra-class correlation coefficient (0.98) has been determined for the prone Yo-Yo IR1 (Chapter 3).

Internal and perceptual responses

Respiratory gas exchange was measured continuously using a portable, breath-by-breath system (Cosmed, K4b^2, Cosmed, Rome, Italy). Before each test, O_2 and CO_2 were calibrated with known concentrations. Upon completion, minute ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) data were averaged over 15-s epochs and matched with distance (based on time) to calculate mean sub-maximal values at 160 m, 280 m and 440 m. Finally, peak values for each variable were considered as the highest value achieved during the test. Previous literature has reported acceptable limits of agreement and mean bias for $\dot{V}_E$ (± 16.3 and ± 1.27 L·min^{-1}), $\dot{V}CO_2$ (± 0.67 and ± 0.06 L·min^{-1}), $\dot{V}O_2$ (± 0.82 and ± 0.08 L·min^{-1}), strong intraclass correlation (>0.75) and low technical error of measurement (<5%) between repeated trials exceeding 3-minutes when using the Cosmed K4 to measure $\dot{V}_E$, $\dot{V}O_2$, and $\dot{V}CO_2$.[79] Heart rate, monitored via telemetry (Polar, FS1, Polar Electro, Oy Finland), was measured continuously during both trials to ascertain mean heart rate (HR_{mean}) at 160 m, 280 m and 440 m, and peak heart rate (HR_{peak}), defined as the highest recorded heart rate during the test.

Fingertip capillary blood samples (5 μL) were taken immediately before and within 30 s of completing the Yo-Yo IR1 tests and analysed for $[La]_b$ (Lactate Pro analyser, Arkay, Kyoto, Japan). To remove any inter-analyser variability, the same Lactate Pro was used throughout (CV = 8.2%). After habituation to the scale and standardized instructions,[203] rating of perceived exertion (RPE; in-house CV = 2.4%) was recorded after 160 m, 280 m, 440 m and at exercise cessation using the Borg 6-20 scale.[27]

External responses

A 10 Hz micro-technology device fitted with a 100 Hz tri-axial accelerometer, gyroscope and magnetometer (Optimeye S5, Catapult Innovations, Melbourne, Australia) was worn in a custom-made vest with the unit positioned between the participant's scapulae. The available satellites and horizontal dilution of precision were 14.2 ± 1.2 (range 12.0–18.0) and 0.6 ± 0.1 (range 0.5–1.6), respectively. To exclude any possible intra-device variability, all participants wore the same GPS unit for each trial. Data were later downloaded and analysed (Sprint Version 5.1, Catapult Sports, VIC, Australia) for relative PlayerLoad™ ($AU \cdot min^{-1}$), HMP (> 20 $W \cdot kg^{-1} \cdot min^{-1}$) and accelerations at 0-2, 2-3, 3-4 and 4-20 $m \cdot s^{-1}$ ($m \cdot min^{-1}$). This micro-technology device is reliable and valid for measuring the movement of team sport athletes.[173]

6.2.4 Statistical analysis

All data are presented as mean ± SD and represent all participants (except for sub-maximal responses at 440 m; *n* = 15). Magnitude-based inferences (MBI) and effect sizes with 90% confidence limits were used, with effect sizes calculated as the difference between trials divided by the pooled SD. This approach was applied to the peak movement, physiological and perceptual responses as well as sub-maximal responses at three distances (160 m, 280 m and 440 m). Threshold values for effect sizes were: 0.0-0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; >2.0, very large.[153] Threshold probabilities for a mechanistic effect based on the 90% confidence limits were: 25-75% *possibly*, 75-95% *likely*, 95-99% *very likely* and > 99.5 *most likely*.[24] If the likely range of a true value overlapped substantially positive or negative values, the change was classified as *unclear*. To ascertain the relationship between the two tests, and with body mass, Pearson's correlation (r) was used to determine the correlation coefficient with the following criteria applied: < 0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect. In addition, linear regression was used to determine how much of the prone Yo-Yo IR1 distance was explained by the Yo-Yo IR1 distance. Statistical analysis was conducted using a predesigned spreadsheet for comparing means,[149], and correlation and regression.[152]

6.3. Results

Total distance was *most likely* lower during the prone Yo-Yo IR1 with a mean difference of -346 ± 115 m. Relative PlayerLoad™ and HMP were *very likely* and *most likely* higher during the prone Yo-Yo IR1 compared to the Yo-Yo IR1, respectively

(Figure 14 and 15). The peak acceleration responses across all thresholds were *likely* to *very likely* higher during the prone Yo-Yo IR1 compared to the Yo-Yo IR1 (Table 9). These higher loads are reflected in the *possibly* to *very likely* higher $\Delta[La]_b$, peak RPE and peak metabolic responses during the prone Yo-Yo IR1 compared the Yo-Yo IR1 (Table 9, Figure 14).

Differences between sub-maximal metabolic and HR responses at 160 m were *unclear*, although there was a *likely* higher RPE during the prone Yo-Yo trial (Table 10). The effect on HR was *unclear* at 160 m and 280 m, but RPE, $\dot{V}_E$, $\dot{V}CO_2$ and $\dot{V}O_2$ were *likely* to *very likely* higher during the prone Yo-Yo IR1 (Table 2). At 440 m, HR was *possibly* lower, while RPE and metabolic responses were *very* to *most likely* higher during the prone Yo-Yo IR1 compared to the Yo-Yo IR1 (Table 10).

There was a large correlation for distance covered between the Yo-Yo IR1 and prone Yo-Yo IR1 (r = 0.87) and linear regression revealed that performance on the Yo-Yo IR1 explained 76% (R^2 = 0.76) of the variance during the prone Yo-Yo IR1. A small and trivial correlation was observed between body mass and the distance covered during prone Yo-Yo IR1 (r = -0.28, 90% CL -0.62 – 0.15) and Yo-Yo IR1 (r = -0.07, 90% CL -0.47 – 0.36), respectively. A small correlation was also observed between body mass and the difference in distance covered between tests (r = -0.27, 90% CL -0.16 – 0.61). Body mass explained 8% (R^2 = 0.08) of prone Yo-Yo IR1 performance, 0.4% (R^2 = 0.004) of Yo-Yo IR1 performance and 7.2% (R^2 = 0.072) of the differences between tests.

Table 9. Peak external and internal responses to the Yo-Yo IR1 and prone Yo-Yo IR1.

	Yo-Yo IR1	Prone Yo-Yo IR1	ES (CL)	Descriptor
External Responses				
Distance (m)	964 ± 222	619 ± 160	-1.87 (-2.06 to -1.68)	*Most likely* ↓
PlayerLoad™ (AU·min^{-1})	13.9 ± 0.9	14.6 ± 1.4	0.70 (0.27 to 1.12)	*Very likely* ↑
High metabolic power (>20W·kg^{-1}·min^{-1})	3.5 ± 0.9	5.3 ± 1.2	1.80 (1.43 to 2.07)	*Most likely* ↑
Acceleration 0-2 m/s (m·min^{-1})	6.2 ± 1.0	6.7 ± 1.6	1.10 (0.41 to 1.73)	*Very likely* ↑
Acceleration 2-3 m/s (m·min^{-1})	6.0 ± 1.0	6.7 ± 0.5	0.62 (0.16 to 1.08)	*Likely* ↑
Acceleration 3-4 m/s (m·min^{-1})	2.9 ± 0.5	3.5 ± 0.9	0.94 (0.47 to 1.41)	*Very likely* ↑
Acceleration 4-20 m/s (m·min^{-1})	2.4 ± 0.6	3.0 ± 0.9	0.78 (0.36 to 1.23)	*Very likely* ↑
Internal Responses				
HR_{peak} (b·min^{-1})	197 ± 8	195 ± 7	-0.26 (-0.51 to -0.02)	*Possibly* ↓
$\Delta[La]_b$ (mmol·l^{-1})	9.2 ± 2.0	9.9 ± 1.2	0.36 (0.10 to 0.72)	*Likely* ↑
RPE (AU)	17.1 ± 1.6	18.2 ± 1.5	0.63 (0.21 to 1.04)	*Very likely* ↑
$\dot{V}_{Epeak}$ (L·min^{-1})	136.7 ± 33.4	144.3 ± 13.8	0.23 (-0.18 to 0.64)	*Possibly* ↑
$\dot{V}O_{2peak}$(mL·min^{-1}·kg^{-1})	48.7 ± 3.8	50.2 ± 4.5	0.37 (-0.02 to 0.76)	*Likely* ↑
$\dot{V}CO_{2peak}$ (L·min^{-1})	4.8 ± 0.37	4.9 ± 0.44	0.26 (-0.15 to 0.68)	*Possibly* ↑

Note: Peak heart rate (HR_{peak}), delta blood lactate concentration $\Delta[La]_b$, rating of perceived exertion (RPE), minute ventilation ($\dot{V}_{Epeak}$), oxygen uptake ($\dot{V}O_{2peak}$) and carbon dioxide production ($\dot{V}CO_{2peak}$). ↑ = increase. ↓ decrease.

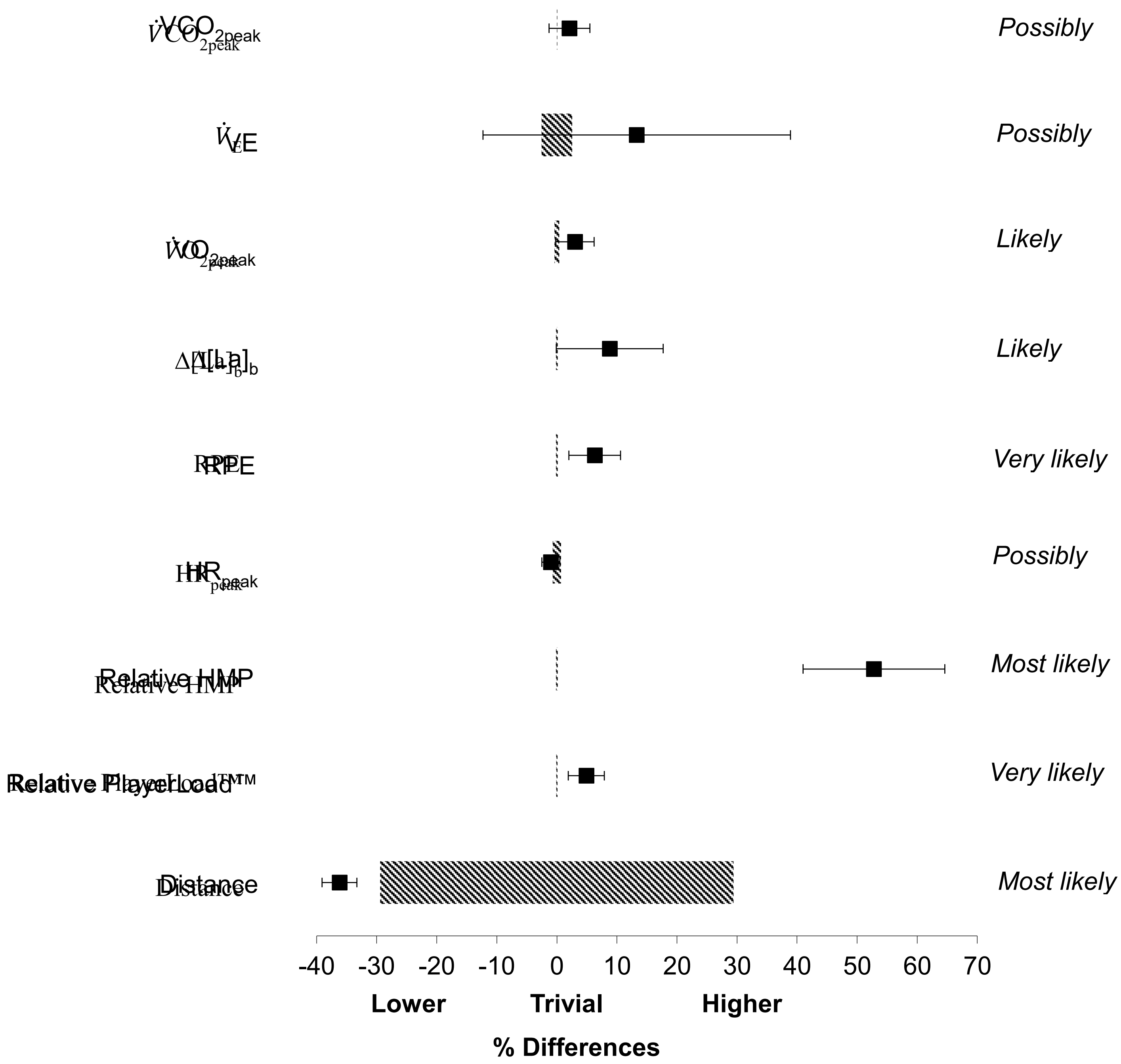

Figure 14. Percentage difference in metabolic, physiological and external responses measured for Yo-Yo IR1 and prone Yo-Yo IR1 (bars indicated uncertainty in the true mean difference with 90% confidence intervals). Trivial areas were calculated from the smallest worthwhile change.

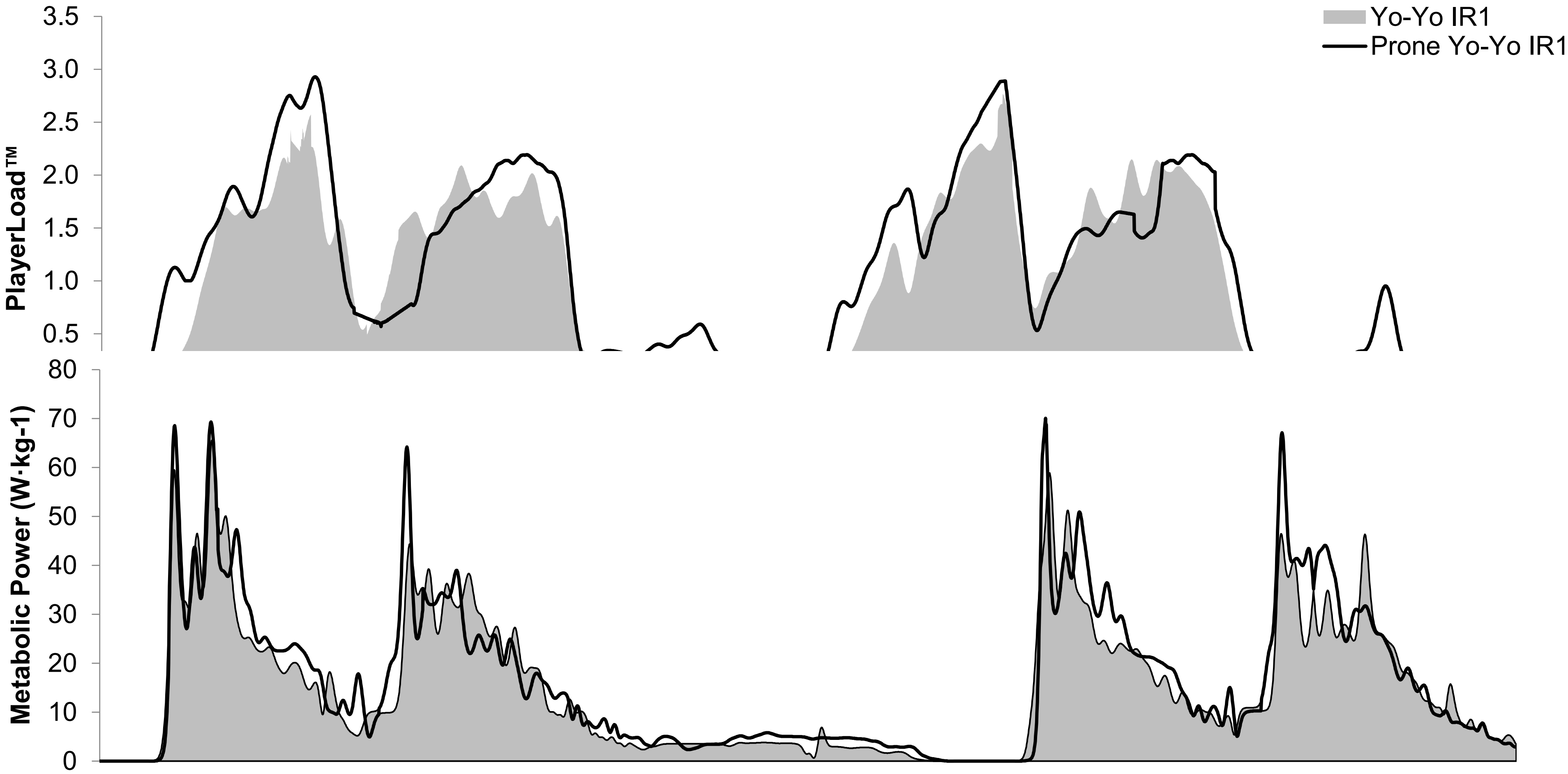

Figure 15. Changes in PlayerLoad™ (upper panel) and metabolic power (lower panel) for one representative participant during two consecutive shuttles at 14 km·h^{-1} during the Yo-Yo IR1 and prone Yo-Yo IR1.

Table 10. Sub-maximal cardiovascular, perceptual and metabolic responses to the Yo-Yo IR1 and prone Yo-Yo IR1

	160 m (*n* = 16)	280m (*n* = 16)	440 m (*n* = 15)
HR_{mean} ($b \cdot min^{-1}$)			
Yo-Yo IR1	138 ± 16	174 ± 10	187 ± 11
Prone Yo-Yo IR1	131 ± 13	172 ± 9	184 ± 10
ES (CL)	-0.37 (-0.96 to 0.21)	-0.20 (-0.33 to 0.74)	-0.25 (0.04 to 0.55)
Descriptor	*Unclear*	*Unclear*	*Possibly* ↓
RPE (AU)			
Yo-Yo IR1	9.7 ± 1.5	13.4 ± 1.4	16.2 ± 2.1
Prone Yo-Yo IR1	10.4 ± 1.5	14.9 ± 1.8	17.6 ± 1.4
ES (CL)	0.40 (-0.06 to 0.87)	0.96 (0.46 to 1.45)	0.76 (0.45 to 1.07)
Descriptor	*Likely* ↑	*Very likely* ↑	*Most likely* ↑
$\dot{V}_E$ ($L \cdot min^{-1}$)			
Yo-Yo IRI1	57.9 ± 10.8	99.4 ± 11.7	122.7 ± 14.9
Prone Yo-Yo IR1	60.4 ± 10.5	114.8 ± 11.6	133.8 ± 13.0
ES (CL)	0.23 (-0.25 to 0.70)	1.20 (0.95 to 1.45)	0.70 (0.43 to 0.97)
Descriptor	*Unclear*	*Most likely* ↑	*Most likely* ↑
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}$)			
Yo-Yo IR1	29.9 ± 3.9	43.2 ± 4.4	45.1 ± 4.4
Prone Yo-Yo IR1	31.1 ± 4.2	45.2 ± 3.5	46.8 ± 4.8
ES (CL)	0.27 (-0.34 to 0.89)	0.48 (0.02 to 0.93)	0.36 (0.23 to 0.48)
Descriptor	*Unclear*	*Likely* ↑	*Very likely* ↑
$\dot{V}CO_2$ ($L \cdot min^{-1}$)			
Yo-Yo IR1	2.2 ± 0.4	3.8 ± 0.4	4.4 ± 0.3
Prone Yo-Yo IR1	2.2 ± 0.4	4.3 ± 0.4	4.7 ± 0.5
ES (CL)	0.13 (-0.44 to 0.69)	1.22 (0.86 to 1.59)	0.67 (0.31 to 1.04)
Descriptor	*Unclear*	*Most likely* ↑	*Very likely* ↑

Note: Mean heart rate (HR_{mean}), rating of perceived exertion (RPE), minute ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O2$) and carbon dioxide production ($\dot{V}CO2$). ↑ = increase. ↓ decrease.

6.4. Discussion

This study investigated the effects of introducing the up-and-down actions typically observed after a tackle on internal and external responses during the Yo-Yo IR1 in rugby players. Consistent with the first hypothesis, participants performing the prone Yo-Yo IR1 elicited greater sub-maximal and peak (except HR_{peak}) metabolic, physiological and movement responses, but covered less total distance. There was a strong agreement between both Yo-Yo IR1 tests, although a proportion of the variance in the prone Yo-Yo IR1 performance did not explain performance in the Yo-Yo IR1 suggesting the prone Yo-Yo IR1 offered insight beyond the traditional test for rugby league players. In contrast to the final hypothesis, only a small relationship was observed between body mass and the prone Yo-Yo IR1.

Total distance was lower during the prone Yo-Yo IR1 compared to standard Yo-Yo IR1 trial. It is likely that the repeated up-and-down action emphasised players having to accelerate to maintain a given speed, which was responsible for a greater energetic demand during the prone Yo-Yo IR1 compared with the Yo-Yo IR1, which in turn, caused earlier exercise cessation. As the audio signal did not account for the time taken to get up from the prone position, participants were required to place greater emphasis on the initial acceleration during this trial to cover the 40 m within the allocated time. Greater distances covered within all acceleration thresholds, higher metabolic power and PlayerLoad™ during the prone Yo-Yo IR1 further support this notion (see Figure 15). Getting up from the floor and accelerating would also increase upper- and lower-body muscle activation at the start of the shuttle. Compared to the standard Yo-Yo IR1, these additional actions would likely result in a greater reliance on fast twitch muscle fibres and subsequent metabolite disturbances that are associated with fatigue, including K+ efflux, which has been reported to impact the transmission of surface member action potential.[2,268] Furthermore, an increase in Pi, adenosine diphosphate (ADP) and a decrease in adenosine triphosphate (ATP) are reported to impact the sarcoplasmic reticulum calcium ion (Ca^{2+}) uptake, and the increase in Pi and H+ ions can lower the pH which negatively impacts on Ca^{2+} activated muscular force.[2,156] It is also important to acknowledge the role of the central nervous system and that an increase in perception of effort and feedback from the muscle afferents might have reduced the neural drive (i.e. greater corollary discharge);[230] thus, potentially explaining the lower distance covered in the prone Yo-Yo IR1.

These results indicate that no practically meaningful difference was observed in sub-maximal or peak heart rate. These findings agree with Haydar, Haddad, Ahmaidi, and Buchheit[139] who reported no differences in HR_{peak} when participants completed several modified (continuous, linear and greater number of changes of direction) $30\text{-}15_{IFT}$ tests. However, the results appear to contrast those of Ashton and Twist,[4] who observed a *possibly* lower HR_{mean} during an intermittent shuttle test with an increased number of directional changes. Whilst it is important to acknowledge that neither study adopted the prone position during their investigations, they provide some, albeit conflicting, evidence regarding changes in HR when the mechanical load is altered during intermittent running. It is noteworthy that HR_{mean} at 400 m and HR_{peak} were *possibly* lower during the latter stages of the prone Yo-Yo IR1 compared to the Yo-Yo IR1, despite the increased acceleratory demands. One possible explanation is the contrasting body positions during the two trials, which might have had a small influence on heart rate.[33] Also, as the prone Yo-Yo IR1 resulted in greater accelerated running during the outward shuttle due to the time lost when getting up, this speed was continued into the inward shuttle unnecessarily (Figure 15). Such an approach likely resulted in participants slowing down towards the end of the inward shuttle, perhaps explaining a slightly lower HR. Nonetheless, it is important to note that the difference between the tests (2-3 $b \cdot min^{-1}$) was of little practical significance when considering the reliability of this measure during the Yo-Yo IR1.[73]

$\dot{V}O_{2peak}$ was *likely* higher during the prone Yo-Yo IR1 at exercise cessation, and was *unclear*, *likely* and *very likely* higher during each of the sub-maximal distances when compared to the Yo-Yo IR1, respectively. These findings agree with Buchheit, Bishop, Haydar, Nakamura, and Ahmaidi[34] who reported *possibly* higher $\dot{V}O_2$ responses when incorporating 180° change of direction during repeated shuttle running. Whilst this protocol is different to that used in the current study, these findings suggest that changes in the mechanical loading through a change of direction or adopting a prone position during shuttle-based and incremental shuttle running can alter the $\dot{V}O_2$ response. These findings are, however, in contrast to those of Hader et al.[132] who reported no differences in O_2 demand during repeated sprinting with and without changes of direction. As the authors note, the increase in O_2 demand associated with changes of direction was probably offset by the reduction in running speed. In contrast, the present study controlled the running speed during both tests, though potential differences in activity (i.e. getting into the prone position) during the rest period should be acknowledged.

Unsurprisingly, $\dot{V}CO_2$ increased as both tests progressed and was higher during the prone Yo-Yo IR1. The higher $\dot{V}CO_2$ reflects an increased metabolism to maintain a higher ATP turnover that was required during the prone Yo-Yo IR1 trial due the greater accelerated running. It is possible that the emphasis on accelerated running was lower at 160 m where the time permitted to cover the 40 m was longer; thus, explaining the unclear difference in $\dot{V}CO_2$ compared to 280 and 440 m. $\dot{V}_E$ was also *possibly* higher at exercise cessation and was *most likely* higher at 280 m and 440 m during the prone Yo-Yo IR1. These results support the notion that during the prone Yo-Yo IR1 there was a greater and earlier reliance anaerobic metabolism which might explain the higher $[La]_b$ and $\dot{V}CO_2$ production. The physiological responses to starting the Yo-Yo IR1 from a prone position are consistent with studies reporting an increased reliance on anaerobic metabolism with accelerated running.[273]

Between-trial differences in RPE revealed a higher perception of effort at each sub-maximal distance and at exercise cessation of the prone Yo-Yo IR1. Such findings might be explained by both peripheral and central factors. Greater and earlier production of metabolic by-products during the prone Yo-Yo IR1 could have activated group III and IV afferents[83] and compromised performance in an attempt to limit disturbances through inhibition of the central motor drive.[3] In contrast, higher RPE during the prone Yo-Yo IR1 might be explained by corollary discharge from premotor and motor areas of the cortex responsible for muscle contraction.[66] If so, these results might suggest that the increase in RPE is a reflection of the greater corollary discharge in order to in maintain the required running speed during the prone Yo-Yo IR1 through greater accelerated running.[230] Whilst is it beyond the scope of this study to determine the exact mechanism, these results support the notion that the addition of starting the Yo-Yo IR1 in the prone position increases an individual’s rating of perceived exertion.

Both versions of the Yo-Yo IR1 could be considered maximal, as evidenced by attainment of (similar) HR_{peak} (< ±10 $b \cdot min^{-1}$ age-predicted HR_{peak}), $[La]_b$ (≥ 8 $mmol \cdot L^{-1}$), near-maximal RPEs and similar $\dot{V}O_{2peak}$ values to those previously reported for rugby union[81] and league players.[98] The large covariance (76%) between tests suggests that both tests can be used to assess intermittent running ability. However, 24% of player performance on the prone Yo-Yo IR1 is not explained by intermittent running (as determined using the Yo-Yo IR1) and likely refers to their ability to get from the prone position and accelerate during the early stages of the outward shuttle. The prone Yo-Yo IR1 therefore allows practitioners to assess distinct characteristics that are specific to collision sports beyond that of the Yo-Yo IR1, including their ability to sustain time above 20 $W \cdot kg^{-1}$ ($r = 0.48$), mean speed ($r = 0.64$), sprint speed (r - 0.71) and repeated sprints ($r = 0.78$) over two bouts of simulated match-play (Chapter 5). Given the importance of such actions during collision sports, it is essential that practitioners can evaluate a player's capability to repeatedly perform these actions.

The trivial and small negative correlations between body mass, distance covered and the change in distance covered between tests suggest a higher body mass has minimal effect on performance during the prone Yo-Yo IR1. These observations contradict those of Darrall-Jones et al.[63] who reported body mass to negatively influence peak running speed, and thus performance, attained in the $30\text{-}15_{IFT.}$ That the players studied by Darrall-Jones et al.[63] were considerably heavier (~15-20 kg) with greater heterogeneity of body mass, might explain these differences. Future studies might explore the relationship between body mass and distance covered during the prone Yo-Yo IR1 further, using a large sample across all playing positions in rugby league.

6.5. Conclusion and practical applications

This study has confirmed that the addition of a rugby-specific action decreases the total distance covered during the Yo-Yo IR1. It is postulated that this change in Yo-Yo IR1 performance is attributed to increases the metabolic, cardiovascular and perceptual responses caused by starting each shuttle from a prone position. This is likely a consequence of greater involvement of the upper-body musculature to get up from the floor quickly and the greater emphasis placed on accelerated running to meet the required running speed. The large covariance between tests suggests that performance on one can, to some degree, explain performance on the other. However, with a proportion of performance not explained by a running-based Yo-Yo IR1, it likely refers to the ability to perform distinct metabolically demanding actions typical of collision sports. Such insight provides justification for using a sport-specific Yo-Yo IR1 test when assessing rugby league players. With no sport-specific test for assessing prolonged high-intensity intermittent running available to rugby league practitioners (Chapter 2), the results of Chapter 5 and those presented here support the use of the prone Yo-Yo IR1 and its inclusion in the RLAP battery. The results of this study have several practical applications. Firstly, the increased metabolic, physiological and perceptual responses elicited by adopting the prone position before accelerated running suggest this is a method that can be used by coaches to modify training load within a periodized plan. This option might be preferable for coaches in the lead up to match-play, enabling exposure to a high training load without the added injury risk that might accompany collisions.[103] In addition, the test allows coaches to evaluate several determinants of rugby specific performance for monitoring purposes over the season and to assess the efficacy of specific training interventions that would not be captured using a running-based test.

Chapter 7

Factors affecting the anthropometric and physical characteristics of elite academy rugby league players: a multi-club study

The systematic review in Chapter 2 highlighted a number of factors that can influence the anthropometric and physical characteristics of rugby league players within the research including season phase, playing age, playing standard and the performance on a specific test due to shared covariance. However, what remains unknown are the factors associated with the change in performance of the RLAP battery despite this having important implications for talent development, the interpretation of results against normative data (Chapter 4), and the potential implications this has on the responses to match-play (Chapter 5). Further, understanding how the anthropometric and physical characteristics change across a season as well as the influence of playing position, training age and league position, for example, would provide valuable insight into the sensitivity of the RLAP battery when considering the reliability of each test (Chapter 3). Therefore, the aim of Chapter 7 was to investigate the contextual factors associated with a change in anthropometric and physical characteristics battery across a competitive season as well as the degree to which a characteristic can influence another using the RLAP battery.

Dobbin, N., Highton, J., Moss, S. L., & Twist, C. (2019). Factors affecting the anthropometric and physical characteristics of elite academy rugby league players: a multi-club study. *International Journal of Sports Physiology and Performance,* doi: 10.1123/ijspp.2018-0631.

7.1. Introduction

The anthropometric and physical characteristics of rugby league players, including stature, body mass, body composition, speed, strength, power, change of direction speed and intermittent running ability,[42] can influence career progression,[242,247] discriminate between selected and non-selected players,[106,257] differentiate between age categories (Chapter 4),[94] influence on-field performance (Chapter 5)[92,169] and have implications for recovery.[169] Furthermore, well-developed physical characteristics might serve to moderate training load and reduce injury risk in team sport athletes.[185,271]

The aforementioned characteristics are potentially influenced by numerous factors, including: playing position (Chapter 7),[198] playing age,[94,255] performance standard (i.e. amateur *cf.* professional),[5,13,94] league position[196] and season phase.[97,196,260] Understanding the role of contextual factors on player characteristics could be informative for coaches, strength and conditioning coaches and sport scientists when monitoring and interpreting player progression. However, the extent to which multiple factors influence a comprehensive range of rugby league players' characteristics have not been explored, likely due to the relatively small samples often used.[13,97,260] Indeed, to the authors knowledge, the only study of this type in team sports was conducted by Mohr and Krustrup,[196] who investigated changes in distance covered during the Yo-Yo Intermittent Running Test Level 2 (Yo-Yo IR2) across an entire league in semi-professional soccer players. This study demonstrated that season phase, playing position, number of appearances and league position all influenced Yo-Yo IR2 performance. For example, the highest ranked five teams covered 8-16% greater distance during the Yo-Yo IR2 compared to the five lowest ranked teams, suggesting that Yo-Yo IR2 might influence team success. The authors also reported that Yo-Yo IR2 distance increased during the pre-season period up to mid-season, before reducing at the end of the season. These findings support the need to consider the independent effects of different factors on player characteristics that are deemed important in team sports.

The use of multi-level mixed modelling has recently been applied to account for the influence of multiple factors on total and relative distance, high-speed distance and metabolic power in rugby league.[70] Such an approach might also be used to explore the independent effects of contextual factors on the anthropometric and physical characteristics of rugby league players, whilst concurrently controlling for other variables. Furthermore, the introduction of each anthropometric and physical characteristic into the model can highlight any interaction between characteristics.[69]

The purpose of this study was therefore to examine the influence of contextual factors on anthropometric and physical characteristics, and their interaction, in elite academy rugby league players from multiple clubs.

7.2. Methods

7.2.1. Participants

With institutional ethics approval, 214 male elite academy rugby league players from five Super League clubs were recruited during the 2016 (*n* = 98/327; 30% of league cohort) and 2017 (*n* = 132/356; 37% of league cohort) season. Of these, 197 players were included in the final analyses, with some individuals competing in both seasons, resulting in a total of 230 ‘player-seasons’ (age 17.3 ± 1.0 years; stature 180.7 ± 6.4

cm; body mass 87.0 ± 10.6 kg) (Figure 16). Skinfold thickness was recorded for 67 ‘player-seasons’ from three clubs.

7.2.2. Study design

A longitudinal observational design was used with anthropometric and physical characteristics assessed at ‘early pre-season’, ‘end of pre-season’, ‘mid-season’ and ‘end of season’. Early pre-season testing took place within the first week of pre-season; end of pre-season after 12 weeks of training; mid-season after 10/11 competitive league matches (out of 20/22); and the end of season after another 10/11 matches. Players represented all playing positions (hooker, halfback, wingers, centre, second row, prop, loose forward, scrum half and stand-off), playing years (1^{st}, 2^{nd} and 3^{rd} years) and were categorised as those playing within top- (top 4), middle- (middle 5) and bottom-ranked (bottom 4) teams based on this final league position in the academy Super League competition (Figure 16). All players completed at least two assessments (mean ± SD = 3.3 ± 0.8) during the season and did not experience any illness or injuries that resulted in 4 weeks or more of missed matches.

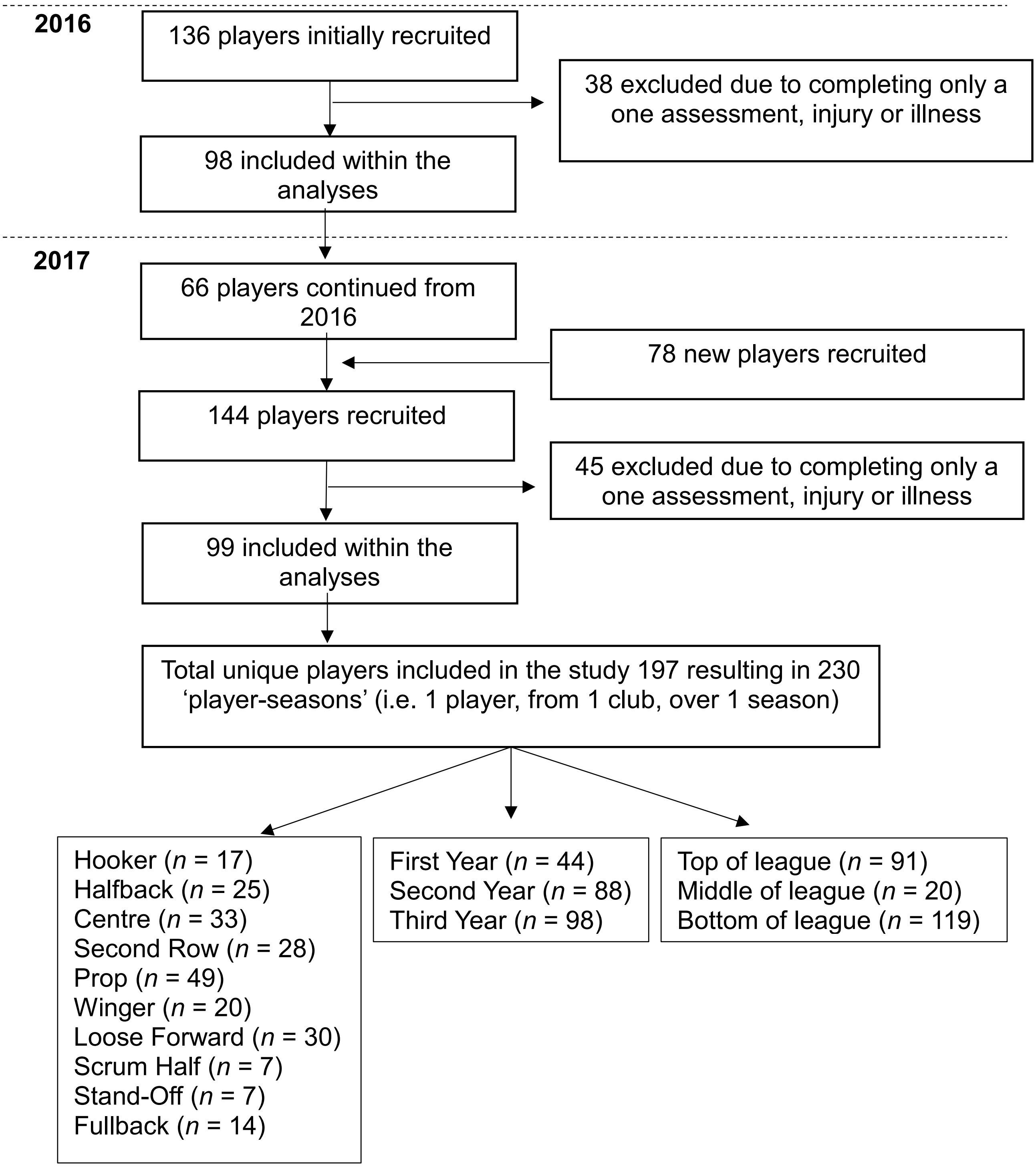

Figure 16. Schematic overview of the recruitment procedures and allocation of players.

Each session was completed at the clubs' training facilities (artificial turf, n = 179; running track, n = 51) after at least 48 hours of rest and at the same time of day. Participants were instructed to arrive in a fed and hydrated state, and were habituated to the testing procedures, which were conducted by the same researcher. Temperature and humidity were typical of the seasonal climate during each session (9.6 ± 1.5 to 17.7 ± 2.6ºC and 72.2 ± 6.2 to 84.8 ± 8.3%).

7.2.3. Procedures

On arrival measures of skinfold thickness (n = 67), stature and body mass were recorded. Thereafter, players completed a warm-up before performing the entire RLAP battery including a 10 m and 20 m sprint test, change of direction test, medicine ball throw, CMJ and prone Yo-Yo IR1. A full overview of the procedures are described in detail in Chapter 3. During each session, players were divided into two groups, with group 1 performing the sprint tests and CMJ first and group 2 completing the change of direction test and medicine ball throw. The groups then swapped and came together for the prone Yo-Yo IR1. The order of tests and groups were standardised for all sessions.

7.2.4. Statistical analysis

Linear mixed modelling was used to determine the independent effects of season phase, playing year, playing position, league ranking, and anthropometric and physical characteristics on each dependent variable (Table 11). Data was checked for normality through visual inspection of normal plots of residuals (Q-Q plot). Once checked, individual players and teams were included as random factors. A "step-up" model was employed beginning with an “unconditional” null-model containing only random factors before fixed factors were introduced and retained upon significantly ($P < 0.05$) altering the model as determined by the maximal likelihood test and χ^2 statistic. The intercept, which represents a modelled value that corresponds to the convergence of all random slopes (i.e. slope for players and teams) once all fixed factors are entered in each model, were derived for each individual’s slope as the height at $x = 0$. However, as none of the continuous fixed factors were measured at 0 (i.e. 0 kg body mass), the origin was shifted using mean centering. The t-statistic was converted to effect size correlations (η^2) and associated 90% confidence intervals (90% CI).[214] Effect size correlations were interpreted as <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; 0.90-0.99, almost perfect; 1.0, perfect.[153] The likelihood of the effect was established using magnitude-based inferences, where quantitative chances of the true effect were assessed qualitatively, as <1%, *almost certainly not*; 1-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, *possibly*; 75-97.5%, *likely*; 97.5-99%, *very likely*; >99%, *almost certainly.*[150] For clarity, only effects that were considered clear (not necessarily significant) were included. Linear mixed models were constructed using SPSS (version 24) and interpreted using a pre-deigned spreadsheet[150] with the full output displayed in Appendix 9.

Table 11. Covariates included in the model specification.

Level of data		Factors	Type	Classification
Level 3	Cluster of clusters	*Team*		
Level 2	Cluster of units (random factor)	*Player ID*		
Level 1	Unit of analysis	*Anthropometric and physical qualities*		
	Dependent variable	Body mass (model 1)	Continuous	kg
		Skinfold thickness (model 2)	Continuous	mm
		10 m sprint time (model 3)	Continuous	s
		20 m sprint time (model 4)	Continuous	s
		Countermovement jump (model 5)	Continuous	cm
		Medicine ball throw (model 6)	Continuous	m
		Change of direction (model 7)	Continuous	s
		Prone Yo-Yo IR1 (model 8)	Continuous	m
	Covariates (fixed factors)	Season phase	Categorical	Early, Late, Mid, End
		Playing age	Categorical	1^{st}, 2^{nd}, 3^{rd} year
		Playing position	Categorical	FB, H, HB, C, SR, P, LF, SH, SO
		League position	Categorical	Top, Middle, Bottom

Prone Yo-Yo IR1 = Prone Yo-Yo Intermittent Recovery Test Level 1; H: Hooker; HB: Halfback; C: Centre; SR: Second Row; P: Prop; LF: Loose Forward; SH: Scrum Half; SO: Stand-off.

7.3. Results

Exploring the interaction between characteristics revealed that body mass was negatively associated with CMJ height (η^2 = -0.26) and prone Yo-Yo IR1 distance (η^2 = -0.16), and positively associated with greater change of direction (η^2 = -0.21) and 20 m sprint (η^2 = 0.08) times (Figure 17). Skinfold thickness was positively associated with body mass (Figure 17). Change of direction time was positively associated with 20 m sprint (η^2 = 0.23), and negatively associated with CMJ (η^2 = -0.16) and prone Yo-Yo IR1 performance (η^2 = -0.15) (Figure 18). Twenty-meter sprint time was positively associated with 10 m sprint performance (η^2 = 0.85) and negatively associated with CMJ (η^2 = -0.31) (Figure 17). Ten-meter sprint time was positively associated with prone Yo-Yo IR1 distance (η^2 = 0.20) (Figure 18). Medicine ball throw was negatively associated with 20 m sprint time (η^2 = -0.06) and positively associated with CMJ performance (η^2 = 0.27) (Figure 19). Body mass, change of direction and 20 m sprint time were negatively associated with prone Yo-Yo IR1 distance.

Body mass was positively associated with season phase as indicated by the *very* to *most likely* higher scores at the end of pre-season, mid-season and end of the season periods (η^2 = 0.15 to 0.30) compared to early pre-season. Skinfold thickness was negatively associated (i.e. lower) with season phase at the end of pre-season through to the end of season when compared to early pre-season (η^2 = -0.31 to -0.68) (Figure 17). Ten-meter sprint (η^2 = -0.20 to -0.29), change of direction (η^2 = -0.17 to -0.39) and 20 m sprint (η^2 = 0.18 to 0.23) performance were positively associated with season phase as indicated by the *most likely* quicker times at end of pre-season through to end of season. Prone Yo-Yo IR1 distance was positively associated with season phase and was greater at end of pre-season, mid-season and end of season (η^2 =

0.22 to 0.54) compared to early pre-season (Figures 18 and 19). Medicine ball throw was positively associated with the mid-season and end of season phases (η^2 = 0.31 and 0.52, respectively). Whilst early pre-season was included as a dummy variable, changes between end of pre-season and mid-season, and mid-season and end of season can be inferred by the size of the effect size correlation. Results indicate that body mass (η^2 = 0.23 *cf.* 0.30), CMJ height (η^2 = 0.28 *cf.* 0.30) and prone Yo-Yo IR1 (η^2 = 0.22 *cf.* 0.54) distance increased and skinfold thickness and 10 m sprint times decreased from the end of pre-season to mid-season. Body mass (η^2 = 0.30 *cf.* 0.15), 10 (η^2 = -0.29 *cf.* -0.25) and 20 (η^2 = 0.18 *cf.* 0.23) m sprint times, CMJ (η^2 = 0.30 *cf.* 0.20) height and prone Yo-Yo IR1 (η^2 = 0.54 *cf.* 0.45) decreased from mid-season to the end of season whilst skinfold thickness increased (η^2 = -0.68 *cf.* -0.60).

Body mass was positively associated with playing year with second- and third-year players heavier (η^2 = 0.16 to 0.17) than first years. Ten-meter sprint time was positively (i.e. slower time) associated with being a third year (η^2 = 0.01).

Large positional variability was observed for measures of body mass and 20 m sprint, CMJ, medicine ball throw and prone Yo-Yo IR1 performance (Figure 17-19). In contrast, less variability was observed between playing positions for skinfold thickness, 10 m sprint time, and change of direction time (Figure 17 & 18).

Positive associations were observed between middle-ranked teams and CMJ height (η^2 = 0.26) whilst prone Yo-Yo IR1 distance was positively associated with top- and middle-ranked teams (η^2 = 0.20 to 0.26; Figure 19C) when compared to bottom-ranked teams.

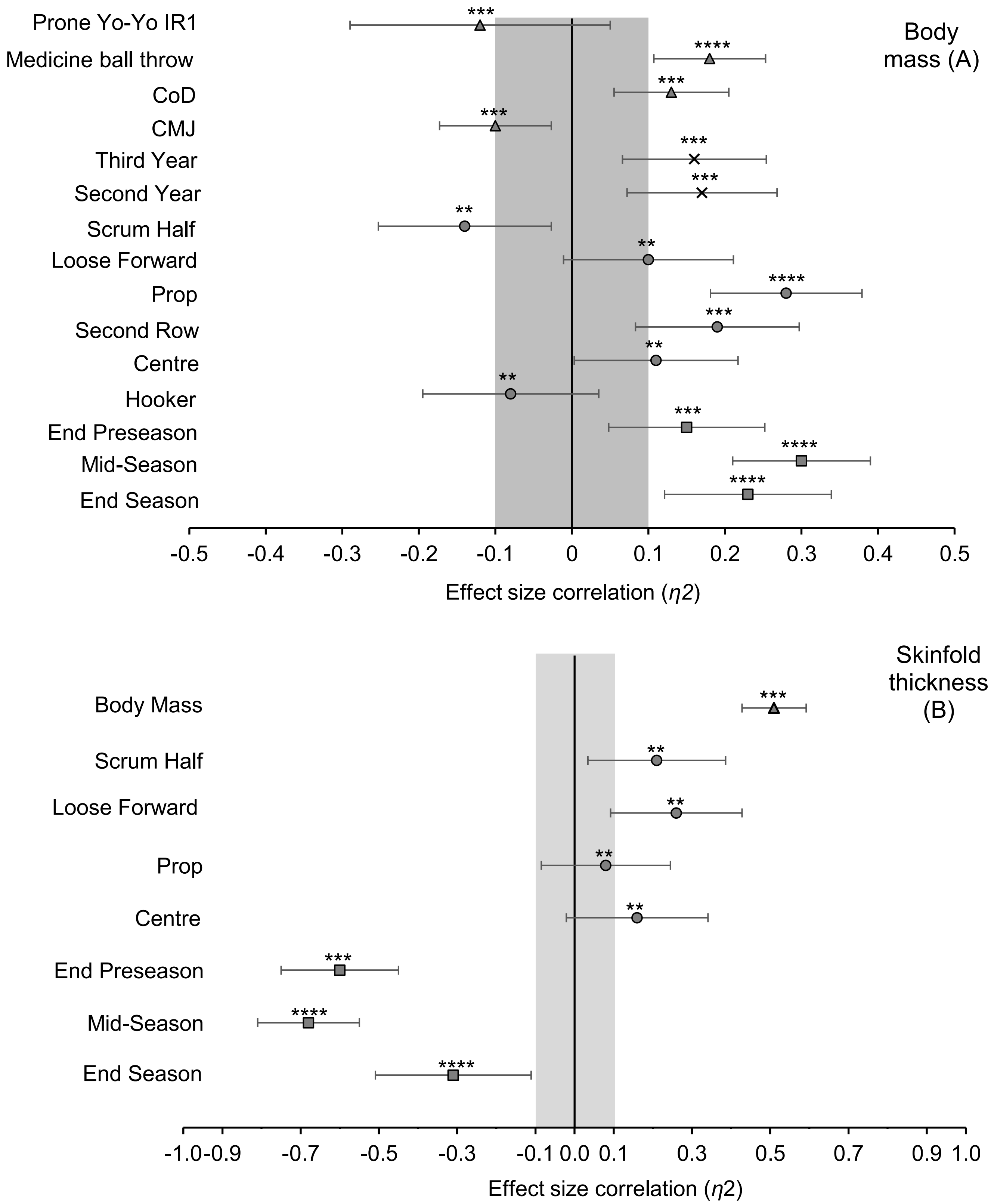

Figure 17. Effect of fixed factors on body mass (A) and skinfold thickness (B).

Note: data expressed as effect size correlation with 90% CI. Effects that crossed 0 were non-significant but demonstrated a clear likelihood effect: ***likely, *** very likely, **** most likely.*

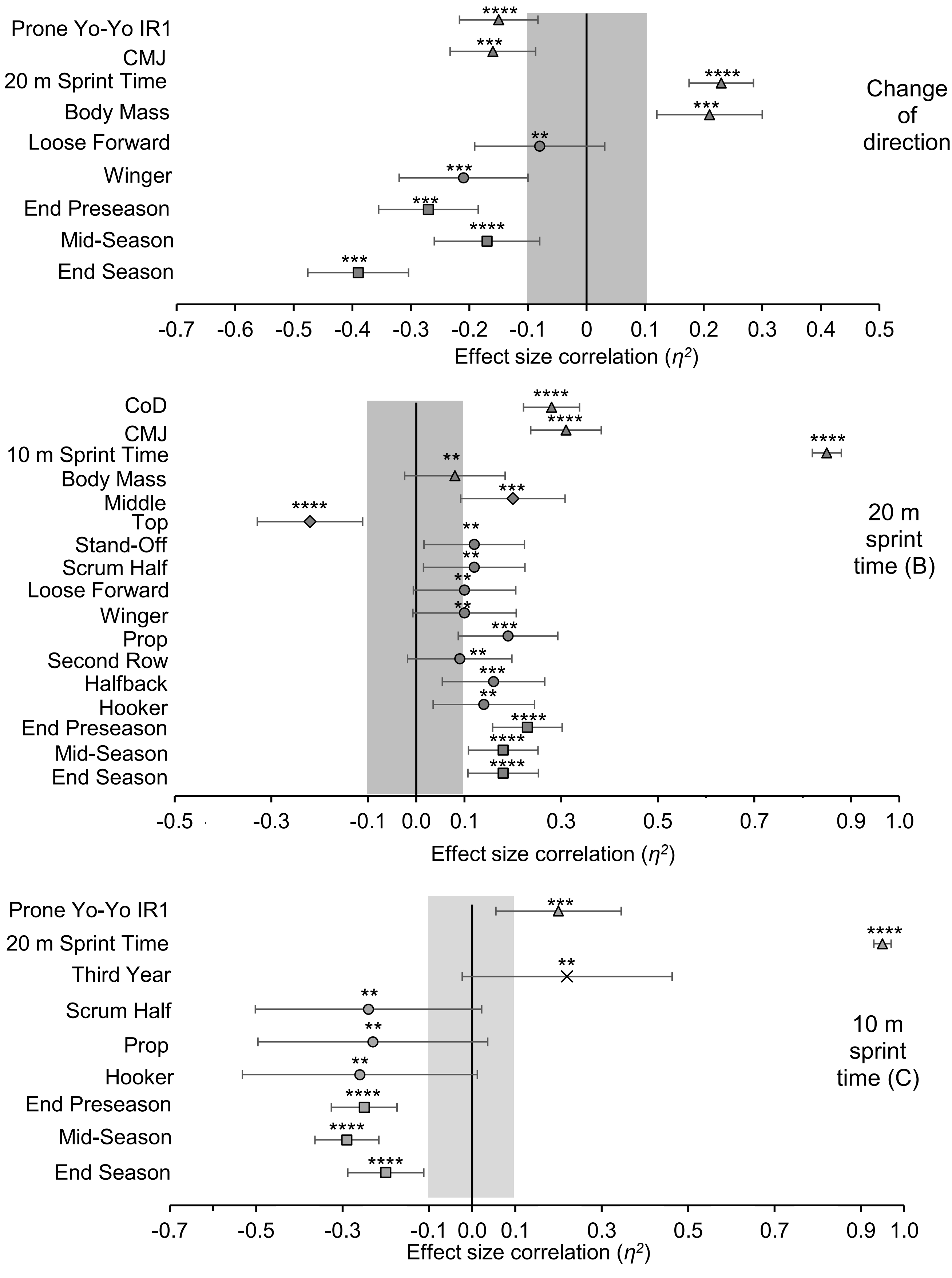

Figure 18. Effect of fixed factors on change of direction time (A), 20 m sprint time (B) and 10 m sprint time (C).

Note: data expressed as effect size correlation with 90% CI. Effects that crossed 0 were non-significant but demonstrated a clear likelihood effect: *** likely, *** very likely, **** most likely.*

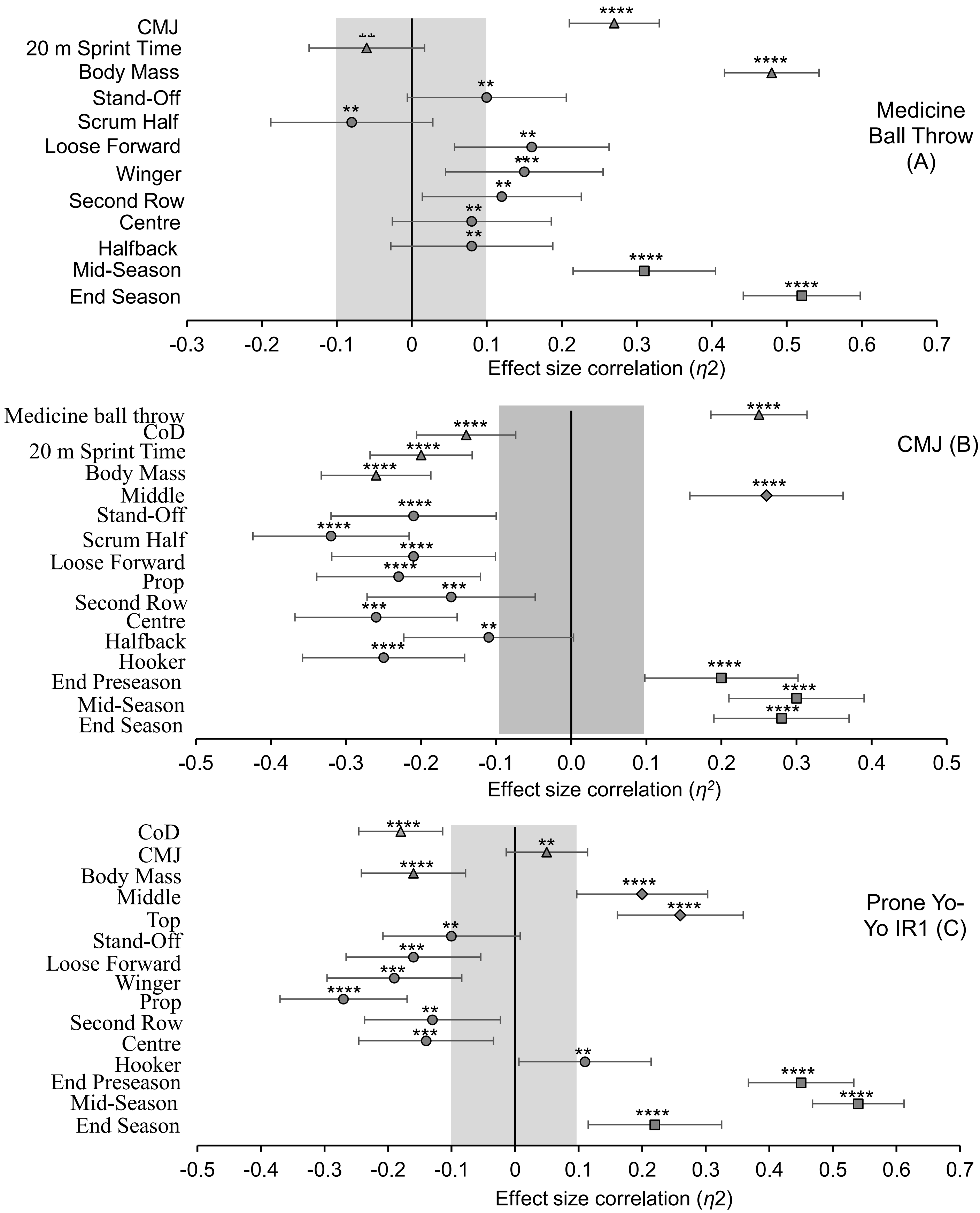

Figure 19. Effects of fixed factors on medicine ball throw (A), CMJ (B) and prone Yo-Yo IR1 (C).

Note: data expressed as effect size correlation with 90% CI. Effects that crossed 0 were non-significant but demonstrated a clear likelihood effect: *** likely, *** very likely, **** most likely.*

7.4. Discussion

This is the first study to assess the influence of multiple factors on the anthropometric and physical characteristics of rugby league players whilst controlling for confounding variables using linear mixed modelling. These results indicated an interaction between several physical characteristics that are influenced by contextual factors including playing position, league ranking, playing age and season phase.

Understanding the interaction between anthropometric and physical characteristics is important for practitioners when developing optimal strength and conditioning practices. For example, Delaney et al.[69] reported a positive relationship between body mass and change of direction time, suggesting a greater body mass can negatively influence change of direction speed. However, they noted that lower-body strength and power training could improve change of direction time without compromising a high body mass. These results indicate that body mass was positively associated with medicine ball throw and negatively associated with change of direction time, CMJ height and prone Yo-Yo IR1 distance. This suggests a focus on increasing body mass in academy players can have both positive and negative effects on certain characteristics and requires consideration with respect to long-term athlete development. Furthermore, CMJ height was positively associated with medicine ball throw and prone Yo-Yo IR1 distance. Indeed, based on the model, an increase in body mass of 1 kg would increase change of direction time by 0.46 s. Therefore, increasing academy players' body mass given its positive association with running momentum[5,198] and ball carrying success in match play[265] would potentially impair change of direction ability, CMJ and intermittent running. Such findings might suggest that increases in body mass should occur at a similar rate to the development of physical characteristics, particularly in youth and academy players who are required to develop holistically as they progress to senior rugby. Understanding the potential impact of developing a specific characteristic on a range of other important determinants of rugby league performance enables practitioners to make more informed training decisions based on individual player objectives.

Playing age influenced body mass with second- and third-year players being heavier than first year players. This finding has been observed elsewhere,[241] and is likely a consequence of both increased training exposure and maturation.[241] These results also indicated a positive association between playing age and 10 m sprint times, suggesting that third year players recorded slower sprint times compared to first years. Slower sprint performance in older academy players has been reported previously[241] and suggests that, despite greater training experience, coaches might place more emphasis on increasing body mass and lean mass in a position-specific manner (i.e. greater focus in forwards) to minimise the discrepancy between academy and senior Super League players.[248] However, such an approach might have a detrimental effect on sprint speed in third year academy players and requires consideration when programming given its influence on ball-carrying success.[265] Whilst these observations suggest increases in body mass might have a detrimental effect on sprint speed, it is important to recognise that body mass continues to increase as players move into senior rugby league,[248] yet the average sprint times are also lower (i.e. faster) (Chapter 4).[94] It is possible that rather than body mass *per se*, it is the rapid increase in body mass required in a short time period (3 years) that negatively impacts on sprinting performance,[193] and that practitioners should look to increase body mass and factors that influence sprinting ability (i.e. force, velocity, power) concurrently.

Dated studies on the physical qualities of senior players[189] and the recent practice of grouping players (e.g. outside backs, adjustable and hit-up forwards)[106] has limited our current understanding of the positional variability within rugby league. Given the large sample size across multiple clubs, this study offered insight into the influence of playing positions on the anthropometric and physical characteristics of academy rugby players. Large between-position variability was observed for body mass, 20 m sprint, medicine ball throw, CMJ and prone Yo-Yo IR1 performance, while low positional variability was observed for skinfold thickness, 10 m sprint time and change of direction time. Variability between positions is likely influenced by the selection of academy players to playing roles based on physical characteristics. For example, larger players are selected into roles that require greater body mass to facilitate greater running momentum and impact forces.[265] Similarly, players with superior intermittent running capacity (e.g. hookers) are best suited to roles that require numerous offensive and defensive involvements.[8] Homogeneity between positions for 10 m sprints and change of direction possibly reflect shared training practices that emphasise speed and agility over short distances because of the limited distance (~10 m) between attacking and defending players during match play and is similar to that observed for 15 and 40 m sprint times across majority of playing positions in senior rugby league.[189] The lack of variability in skinfold thickness between positions probably reflects the generic nutritional advice provided to academy rugby league players and the regular monitoring of body composition (Appendix 13).

To the author's knowledge, no study has explored the differences in anthropometric and physical characteristics based on league ranking in rugby league. These findings concur with those reporting *small* to *large* differences between elite and sub-elite players in rugby league[257] and the results of Mohr and Krustrup[196] who reported an 18-20% greater Yo-Yo IR2 distance in top- and middle-ranked teams compared to bottom-ranked teams in semi-professional soccer. Whilst it is likely that numerous factors influence a team's league ranking, these results suggest that well-developed sprinting ability and rugby-specific intermittent running might be important for success.

In agreement with previous research,[97,196] season phase influenced the anthropometric and physical characteristics of rugby league players. All measures (except medicine ball throw) improved during the pre-season period and continued to improve until mid-season. Between the mid- and late-season phases, change of direction time and medicine ball throw distance continued to improve, whereas body mass, 10 m sprint, CMJ and prone Yo-Yo IR1 performance decreased, and skinfold thickness increased. These results suggest the RLAP battery is sensitive to changes across a season with the observed reduction in training load over the course of the season potentially explaining this finding,[97] Given the influence some anthropometric and physical characteristics have on fatigue[169] and their potential moderating effects on the workload-injury relationship,[1843,271] these findings have important implications for optimal performance capabilities of players (and teams) at the end of the season. With this in mind, future research might explore methods of maintaining the anthropometric and physical characteristics of players during the latter stages of the competitive season that do not simultaneously compromise match performance capability.

Despite the novel approach employed, this study is not without limitations. While this study uses a large data set from several clubs, the data still only represent approximately a third of players in the entire league and is susceptible to the individual selected clubs' approaches to talent identification and development. Furthermore, the researcher was unable to document the ethnicity and maturation status of players. Due to the difficulties standardising measures of training and match load across multiple clubs, this study cannot confirm the proposed reductions in training load that have been reported previously and whether these were responsible for the changes in physical qualities.[97] This research did not include any measures of skill-based performance or muscle strength despite these being important in rugby league.[241] Future research should look to explore these limitations by incorporating the RLAP battery league-wide, including measures of rugby skills, alongside practical measures of training and match load.

7.5. Conclusions and practical applications

The findings of this study highlight the importance of considering multiple factors when interpreting a player's anthropometric and physical characteristic. Furthermore, this study highlights the interaction between physical characteristics assessed using the RLAP battery and suggest that practitioners need to consider both the positive and negative consequences of developing particular characteristics and align this with the player's developmental stage. For example, strength and conditioning coaches working with youth and academy players should look to manage the increase in a player's body mass and improve physical characteristics concurrently. Furthermore, these results underline the importance of considering contextual factors such as playing year and position when assessing or comparing players to national performance standards or selected groups (i.e. first team). It is demonstrated how league ranking and season phase influence several anthropometric and physical characteristics, suggesting practitioners should look to maximise the development of body mass, linear sprint speed, CMJ and intermittent running during the pre-season period and strive to maintain these over the course of the competitive season using appropriate training modalities and training loads.

Using a large sample from multiple clubs, this chapter reports on several factors that influence the anthropometric and physical characteristics of academy rugby league players. Firstly, practitioners should note the covariance between several anthropometric and physical characteristics when planning strength and conditioning programmes. These results also indicate that playing position, league ranking, playing age and season phase influence the anthropometric and physical characteristics of rugby league players. Such insight can be used by practitioners to develop individual players based on their playing position and playing age. Practitioners should also consider the in-season training loads in order to negate any negative changes in anthropometric and physical characteristics, particularly towards the latter stages where teams might be looking to succeed in competitions.

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Chapter 8

The effects of in-season, low-volume sprint interval training with and without sport-specific actions on the physical characteristics of elite academy rugby league players

A key finding in Chapter 7 was the impaired performance of some characteristics between the middle and end of season. Therefore, given the importance of maintaining physical qualities to optimise player performance capability and reduce injury risk, a logical progression of the thesis was to establish if the RLAP battery was sensitive enough to detect changes in physical qualities after a typical training intervention that might be implemented with players during the latter part of the competitive in-season. Further to this, Chapter 5 identified that modifications to the Yo-Yo IR1 by the addition of rugby-league specific actions (i.e. up and down) improved its concurrent validity for rugby league players. Chapter 6 also established that modifying the Yo-Yo IR1 resulted in changes to the movement and physiological response to this test. It followed that whether the prone Yo-Yo IR1 was more sensitive to detect changes after training that did and did not use sport-specific actions would further enhance the tests utility in a real-world setting beyond what had already been established in Chapter 4 and Chapter 7.

Dobbin, N., Highton, J., Moss, S. L., & Twist, C. (in press). The effects of in-season, low-volume sprint interval training with and without sport-specific actions on the physical characteristics of elite academy rugby league players. *International Journal of Sports Physiology and Performance.*

8.1. Introduction

The physical demands of rugby league requires players to perform high-intensity efforts that include high-speed running, sprinting, changing direction, tackling and wrestling.[91] These characteristics are essential for players to succeed[91] and should be central to rugby league conditioning practices.[203] Developing the physical characteristics of rugby league players is the focus of pre-season (Chapter 7, Appendix 13); thereafter emphasis is placed on recovery, technical and tactical development, and match preparations.[95] This change in focus and reduced exposure to maximal-intensity work during training might explain the observed reductions in physical characteristics such as high-intensity intermittent running ability, sprint speed and lower-body power during the latter stages of a ~28-week season (Chapter 7). For example, in Chapter 7, it was reported that prone Yo-Yo IR1, 10 and 20 m sprint times and countermovement were impaired when compared to mid-season and were returning to preseason values. Considering the importance often placed on the final stages of the season (i.e. finals), finding an effective strategy to maintain key performance characteristics as well as determining if the RLAP battery is sensitive to detect these changes could be important for rugby league practitioners. As noted in the systematic review, sensitivity is an important measurement property of any test, particularly those assessing the anthropometric and physical characteristics of rugby league where short-, medium- and long-term adaptations are a continuous focus as players progress from TID programmes through to professional rugby league.

Low-volume sprint interval training (SIT) might be appealing during the season where players can be exposed to maximal-intensity activity through a reduced workload that also enables coaches to address technical and tactical aspects of the game.[183] It is well-documented that SIT (~20-30 s) offers an effective strategy for inducing rapid physiological remodelling[87,158] and increasing physical 'fitness' in athletic populations.[84,183] Moreover, improvements in intermittent- and endurance-based exercise performance have been observed after only two weeks of SIT[38,183,239] and are attributed to morphological and metabolic adaptations within the skeletal muscle[38,183,239] and improved cardiorespiratory capacity.[38,1831] However, whilst SIT appears effective for promoting adaptation, current research is largely limited to soccer players.[158,183,239] Studies have also failed to report the responses to this additional load during the intervention period, which is essential for managing the training load and determining the efficacy of SIT. The activity type should also be considered given the phase of implementation, such that SIT protocols containing metabolically demanding actions (i.e. changing direction or accelerating) and/or sport-specific actions (i.e. tackling), are likely to impose a greater systemic physiological load (Chapter 6).[201] Indeed, in Chapter 6, it was reported that the inclusion of an up/down action during a test of high-intensity intermittent running ability elicited small to moderate increases in $\dot{V}O_{2peak}$, $\dot{V}CO_{2peak}$, $\dot{V}E_{peak}$ and RPE as well as moderate to large increases in PlayerLoad™, time at HMP and acceleration loads. Whether the inclusion of an up/down action has any effect on physiological adaptation and responses to SIT remains unknown and warrants investigation given its association with running performance in rugby (Chapter 5). Finally, it is important to consider players' ability to tolerate in-season SIT in order to ensure this training modality incurs no detrimental effects within this period.

Accordingly, this study aimed to 1) examine the effectiveness of an in-season, low-volume rugby-specific and running SIT intervention on the physical characteristics of elite academy rugby league players; 2) determine the sensitivity of the RLAP battery for detecting changes in physical characteristics, 3) determine any between-group differences in internal, external and perceptual loads during the SIT interventions and to document the accumulated training load; and 4) explore the wellbeing and neuromuscular responses to the intervention.

8.2. Methods

8.2.1. Participants

Thirty-one elite academy rugby league players (age = 17.1 ± 1.0 y, stature 179.6 ± 5.8 cm, body mass 86.9 ± 5.8 kg) were recruited from two Super League clubs. All players across the two clubs were assigned to a rugby-specific ($SIT_{r/s}$, *n* = 15) or running (SIT_r, *n* = 16) SIT intervention, with the minimization approach used to balance both training groups for playing position and rugby-specific intermittent fitness using the prone Yo-Yo IR1.

8.2.2. Study design

A parallel two-group matched-work experimental design was used to assess the effects of two SIT interventions on the physical characteristics of academy rugby league players. The intervention followed that of Macpherson and Weston[184] and involved players completing six sessions over a 2-week period during the competitive season. The intervention period coincided with a mid-season break in the teams' fixtures (i.e. week 12-14 of a 28-week season), though players completed their normal training during this period. The prescribed sessions replaced all conditioning practices with 24-48 hours between sessions. Institutional ethics approval and informed consent were obtained before starting the study.

8.2.3. Procedures

Training intervention

The intervention involved six sessions over a 2-week period with each session including 6 (week 1) or 8 (week 2) 30 s repetitions of maximal shuttle sprinting. Both interventions required the participant to complete as many shuttles as possible in the 30 s period with a high degree of verbal encouragement given by the lead researcher. The $SIT_{r/s}$ group were required to adopt a prone position at the start of each 20 m shuttle whilst the SIT_r group remained on their feet throughout. A 3-minute active recovery (walking at 1.1 $m \cdot s^{-1}$) followed each 30 s repetition.

Outcome measures

To assess the effectiveness of the intervention, the RLAP battery used was conducted before and after the two-week intervention period. In all, this involved completing a standardised warm-up before performing two 10 m and 20 m sprints; a change of direction test on the left and right sides; two medicine ball throws; two CMJs; and prone Yo-Yo IR1. Full details of the RLAP procedures can be found in Chapter 3.

All testing took place at each club's own training ground at the same time of day on artificial turf and was preceded by 48 hours of no leisure- or club-based physical activity. To control for the influence of diet, participants recorded all food and fluid intake in the 3-hours before the testing sessions and were asked to refrain from caffeine consumption on the day of testing (ES ± 90% CL between pre- and post-testing: carbohydrate = 0.02 ± 0.05; protein, = -0.02 ± 0.08; fat = -0.03 ± 0.07). The same researcher conducted all testing and training sessions in a standardised order with two club coaches present but who refrained from giving verbal encouragement.

All participants were familiar with the testing procedures. Players provided an RPE for all activities 30 min after training using a 10-point scale, which was then multiplied by the duration to provide a measure of training load (sRPE).[85]

Measures of internal and external loads were collected during the pre- and post-intervention prone Yo-Yo IR1, and SIT interventions, whilst perceptual responses were collected during SIT only. Heart rate was measured continuously during the pre- and post-intervention prone Yo-Yo IR1 (Polar, FS1, Polar Electro Oy, Finland) to ascertain mean heart rate (HR_{mean}) at 160, 280 and 440 m, and to compute heart rate recovery (HRR), defined as the number of beats recovered in the 60 s after cessation of the prone Yo-Yo IR1. During all SIT sessions, HR was measured for the entire session and expressed as a percentage of peak HR ($\%HR_{peak}$).

A 10 Hz microtechnology device fitted with a 100 Hz triaxial accelerometer, gyroscope and magnetometer (Optimeye S5, Catapult Innovations, Melbourne, Australia) was worn with the unit harnessed between the scapulae. Participants wore the same unit throughout the study. The available satellites and horizontal dilution of precision were 16.7 ± 0.8 and 0.7 ± 0.1, respectively. After the pre- and post-intervention prone Yo-Yo IR1, the data were downloaded (Sprint Version 5.1, Catapult Sports, Victoria, Australia) and analysed for PlayerLoad™ (AU), time above > 20 $W \cdot kg^{-1}$ (HMP) and distance accelerating above 3 $m \cdot s^{-2}$ (m) at 160, 280 and 440 m. For the SIT sessions, total distance (m), time above HMP, distance covered above 3 $m \cdot s^{-1}$ (m) and mean speed (%peak speed derived from GPS during a 20 m sprint) were analysed.

Before the intervention, participants were habituated to the CR100® scale and educated about the purpose of differential RPE (dRPE). With this knowledge, players were asked to differentiate between central (i.e. breathlessness [dRPE-B]) and local (i.e. legs [dRPE-L]) ratings of exertion 15 to 30 minutes after each $SIT_{r/s}$ and SIT_s session and on their own. To eliminate an order effect, players provided ratings in a randomised order across the sessions. In addition, players provided ratings of perceived fatigue, soreness, sleep quality, mood and stress using a 1-5 Likert scale before each session. All players were familiar with the questionnaire and were asked to complete this away from teammates and coaches. Neuromuscular function was assessed during a CMJ using the same procedures described in Chapter 1.

8.2.4. Statistical analysis

Within-group changes were analysed using a post-only crossover spreadsheet,[148] and between-group changes analysed using a pre-post parallel-groups spreadsheet,[148] with the uncertainty of estimates expressed as 90% confidence intervals (90% CL). In analysing the changes in RLAP scores, and the change in CMJ and wellbeing between groups over time, the baseline (pre-intervention/session 1) variable as a covariate to control for baseline imbalances between groups. To provide an interpretation of the magnitude of change, effect sizes (ES) were calculated as the difference between trials divided by the pooled SD derived from both interventions and the following thresholds applied: 0.0-0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; >2.0, very large.[151] Changes were determined mechanistically with inferences qualified using the following scale: 25% to 75%, *possibly*; 75% to 95%, *likely*; 95% to 99.5%, *very likely*; and >99.5%, *most likely*.[25] In instances when the confidence limits overlapped both substantially positive and negative thresholds, the change was interpreted as unclear.

	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	Game day
Team 1	Testing	Rest	Session 1	Rest	Session 2	Rest	Session 3	Session 4	Rest	Session 5	Rest	Session 6	Rest	Rest	Testing	Rest	Rest	Captains run	Game
Team 2	Testing	Rest	Session 1	Session 2	Session 3	Rest	Session 4	Session 5	Rest	Session 6	Rest	Rest	Testing	Rest	Training	Training	Rest	Captains run	Game

Figure 20. Schematic overview of the two-week study period.

8.3. Results

Within- and between-group analysis on physical characteristics and HRR are presented in Table 12. Between-group differences were trivial for CMJ, change of direction time and medicine ball throw distance; small for 10 m sprint time; and unclear for 20 m sprint time, prone Yo-Yo IR1 distance and HRR.

Sub-maximal internal and external responses during the prone Yo-Yo IR1 along with within-group and between-group analysis are presented in Table 13. Results revealed trivial to small positive within-group changes in HR_{mean} and a trivial between-group difference at 160 m. Small to very large within-group changes were observed in time spent at HMP, PlayerLoad™, and distance accelerating above 3 m·s^{-2}, with unclear to moderate between-group differences.

Training load across the intervention period is presented in Figure 21, with unclear between-group differences observed across all sessions for skills (ES ± 90% CL = 0.06 ± 0.51), SIT (0.04 ± 0.30) and resistance training (0.05 ± 0.31). Moderate differences in the response to $SIT_{r/s}$ and SIT_r were observed for distance (108.6 ± 12.7 *cf.* 118.3 ± 10.2 m), time at HMP (17.2 ± 2.3 *cf.* 14.6 ± 2.5 s) and distance accelerating above 3 m·s^{-2} (9.0 ± 3.0 *cf.* 7.0 ± 2.0 m). A very large difference in mean speed was observed between $SIT_{r/s}$ and SIT_r (60.3 ± 3.5 *cf.* 67.6 ± 4.0 %peak speed). Small differences were observed between $SIT_{r/s}$ and SIT_r in HR_{mean} (154 ± 9 *cf.* 151 ± 12 b·min^{-1}), dRPE-L (74 ± 14 *cf.* 74 ± 13 AU) and dRPE-B (65 ± 18 *cf.* 62 ± 13 AU) (Figure 22).

Small to moderate reductions in perceived wellbeing were observed during the intervention period (ES -0.23 to -1.02); albeit with no clear mean difference between session 1 and 6 (Figure 23). Neuromuscular function demonstrated a trivial to small reduction across the intervention period (ES = -0.52 to 0.28) with no clear mean difference between session 1 and 6 (Figure 23).

Table 12. Outcome measures at baseline with the mean change and qualitative inference for the within- and between-group comparison.

	$SIT_{r/s}$ (*n* = 15)			SIT_r (*n* = 16)			Group Comparison	
	Baseline	Change in score (mean ± SD; ±90%CL)	Qualitative inference	Baseline	Change in score (mean ± SD; ±90%CL)	Qualitative inference	Between-group difference (mean; 90%CL)	Qualitative inference
10 m sprint (s)	1.76 ± 0.08	-0.07 ± 0.05; ±0.03	Moderate +ve***	1.78 ± 0.08	-0.05 ± 0.04; ±0.02	Small +ve***	0.02; ±0.03	Small* favouring $SIT_{r/s}$
20 m sprint (s)	3.02 ± 0.11	-0.07 ± 0.06; ±0.03	Moderate +ve***	3.05 ± 0.10	-0.06 ± 0.05; ±0.02	Small +ve***	0.01; ±0.03	Unclear
CMJ flight time (s)	0.58 ± 0.04	0.02 ± 0.01; ±0.01	Small +ve**	0.58 ± 0.03	0.01 ± 0.01; ±0.01	Small +ve****	-0.01; ±0.01	Trivial*
Change of direction (s)	19.79 ± 0.71	-0.37 ± 0.25; ±0.11	Small +ve***	19.53 ± 0.60	-0.35 ± 0.24; ±0.11	Small +ve***	0.02; ±0.15	Trivial**
Medicine ball throw (m)	7.5 ± 0.8	0.2 ± 0.2; ±0.1	Small +ve**	7.6 ± 0.7	0.2 ± 0.2; ±0.1	Small +ve**	0.0; ±0.13	Trivial**
Prone Yo-Yo IR1 (m)	821 ± 215	120 ± 103; ±46	Small +ve***	863 ± 266	112 ± 92; ±41	Small +ve***	-8; ±60	Unclear
HRR (b·min^{-1})	20	8 ± 5; ±2	Large +ve****	21 ± 5	8 ± 5; ±2	Large +ve****	0.02; ±3.04	Unclear

Abbreviations: $SIT_{r/s}$, rugby-specific sprint interval training; SIT_r, running only sprint interval training; CMJ, countermovement jump; HRR, heart rate recovery.

*Notes: Data presented as mean ± standard deviation. Within-group comparison: +ve, beneficial (positive) effect; -ve, harmful (negative) effect. Between-group comparison: +ve, beneficial (positive) effect of $SIT_{r/s}$ when compared to SIT_r; -ve, harmful (negative) effect of $SIT_{r/s}$ when compared to SIT_r. * possibly (25-75%), ** likely (75-95%), *** very likely (95-99.5), **** most likely (> 99.5%).*

Table 13. Sub-maximal internal and external response during the prone Yo-Yo IR1 at baseline with mean change and qualitative inference for the within- and between-group comparisons.

	$SIT_{r/s}$ (n = 15)			**SIT_r (n = 16)**			**Group Comparison**	
	Baseline	Change in score (mean ± SD; ±90%CL)	Qualitative inference	Baseline	Change in score (mean ± SD; ±90%CL)	Qualitative inference	Between-group difference (mean; ±90%CL)	Qualitative inference
HR_{mean} ($b \cdot min^{-1}$)								
160 m	168 ± 7	-3 ± 3; 1.3	Small +ve***	166 ± 13	-2.7 ± 3.8; 1.7	Trivial +ve*	1; ±2	Trivial**
280 m	183 ± 6	-3 ± 4; 1.6	Small +ve**	181 ± 9	-2.6 ± 4.3; 1.9	Small +ve*	0; ±3	Unclear
440 m	189 ± 5	-3 ± 3; 1.6	Small +ve***	186 ± 8	-2.7 ± 3.0; 1.4	Small +ve**	0; ±2	Unclear
Time > HMP (s)								
160 m	17.2 ± 1.9	-1.9 ± 1.5; 0.7	Moderate +ve****	17.4 ± 1.8	-1.7 ± 1.4; 0.6	Moderate +ve****	0.2; ±0.9	Unclear
280 m	17.8 ± 1.3	-1.3 ± 0.6; 0.3	Moderate +ve****	17.6 ± 1.9	-1.1 ± 0.9; 0.6	Small +ve***	0.2; ±0.5	Trivial*
440 m	22.8 ± 1.1	-2.2 ± 1.5; 0.8	Large +ve****	21.4 ± 1.4	-1.2 ± 0.9; 0.3	Moderate +ve****	1.0; ±0.9	Moderate** favouring $SIT_{r/s}$
PlayerLoad™ (AU)								
160 m	20.3 ± 2.5	-0.6 ± 0.8; 0.4	Trivial +ve*	20.6 ± 2.6	-0.5 ± 1.5; 0.7	Small +ve*	0.0; ±0.7	Unclear
280 m	15.4 ± 2.6	-0.8 ± 0.9; 0.4	Small +ve**	15.8 ± 2.0	-0.6 ± 1.1; 0.5	Small +ve**	0.2; ±0.6	Trivial**
440 m	20.5 ± 2.9	-1.5 ± 1.0; 0.4	Small +ve***	21.3 ± 2.2	-0.9± 1.2; 0.5	Small +ve***	0.6; ±0.7	Small* favouring $SIT_{r/s}$
Distance > 3 $m \cdot s^{-2}$ (m)								
160 m	7.6 ± 1.1	-2.4 ± 1.0; 0.4	Very large +ve****	7.5 ± 1.4	-1.8 ± 1.1; 0.5	Large +ve****	0.6; ±0.6	Small** favouring $SIT_{r/s}$
280 m	7.0 ± 1.4	-2.4 ± 1.3; 0.8	Large +ve****	6.9 ± 1.5	-1.9 ± 1.3; 0.7	Moderate +ve****	0.6; ±0.8	Small* favouring $SIT_{r/s}$
440 m	8.1 ± 1.5	-1.9 ± 1.51 0.5	Large +ve****	7.9 ± 1.4	-1.4 ± 1.2; 0.5	Moderate +ve***	0.5; ±0.7	Small* favouring $SIT_{r/s}$

Abbreviations: $SIT_{r/s}$, rugby-specific sprint interval training; SIT_r, sprint interval training; HR_{mean}, mean heart rate; HMP, high metabolic power.

*Notes: Data presented as mean ± standard deviation. Within-group comparison: +ve, beneficial (positive) effect; -ve, harmful (negative) effect. Between-group comparison: +ve, beneficial (positive) effect of $SIT_{r/s}$ when compared to SIT_r; -ve, harmful (negative) effect of $SIT_{r/s}$ when compared to SIT_r. * possibly (25-75%), ** likely (75-95%), *** very likely (95-99.5), **** most likely (> 99.5%).*

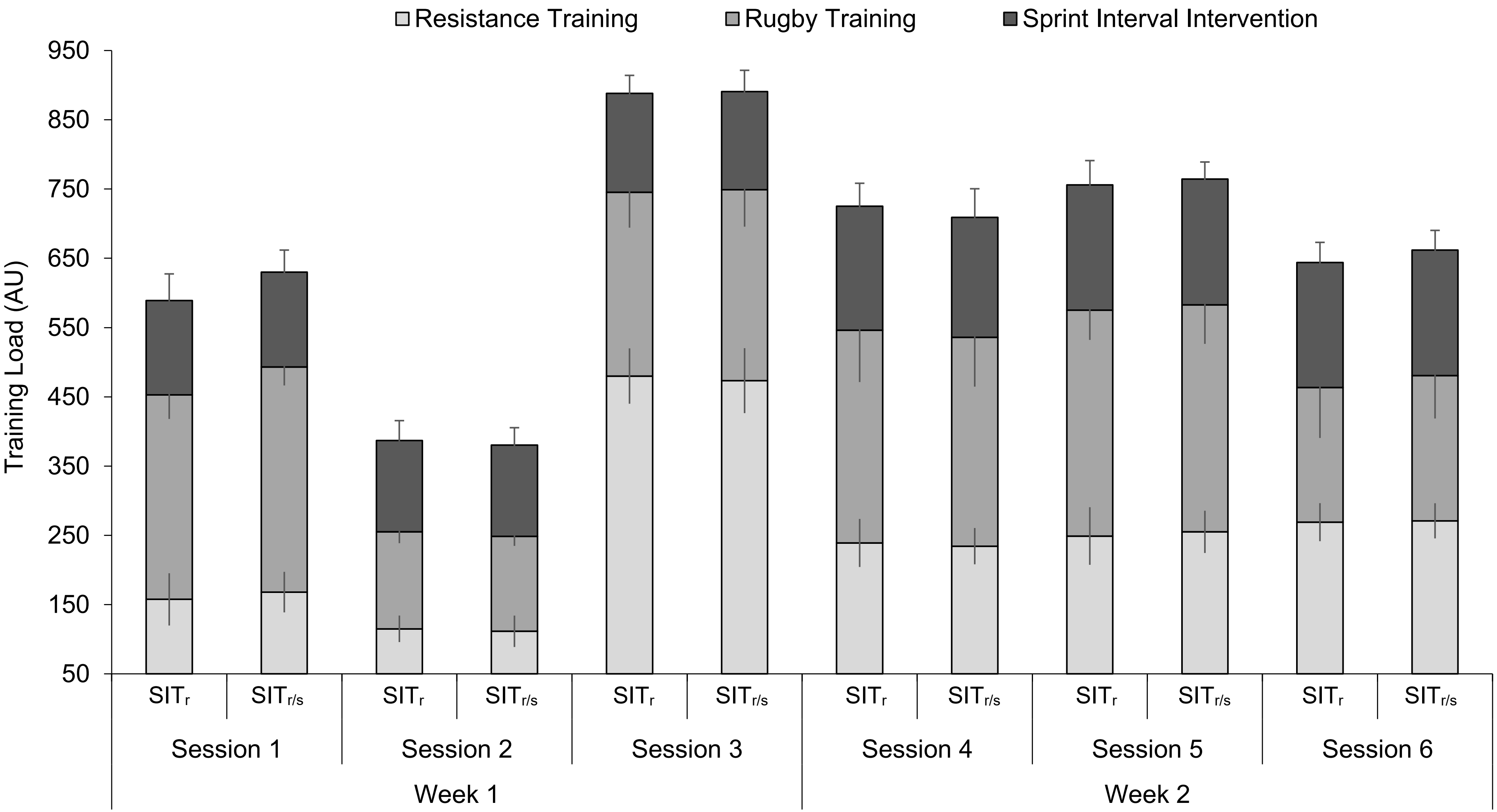

Figure 21. Schematic showing training load for all resistance, rugby and sprint interval sessions across the two-week intervention.

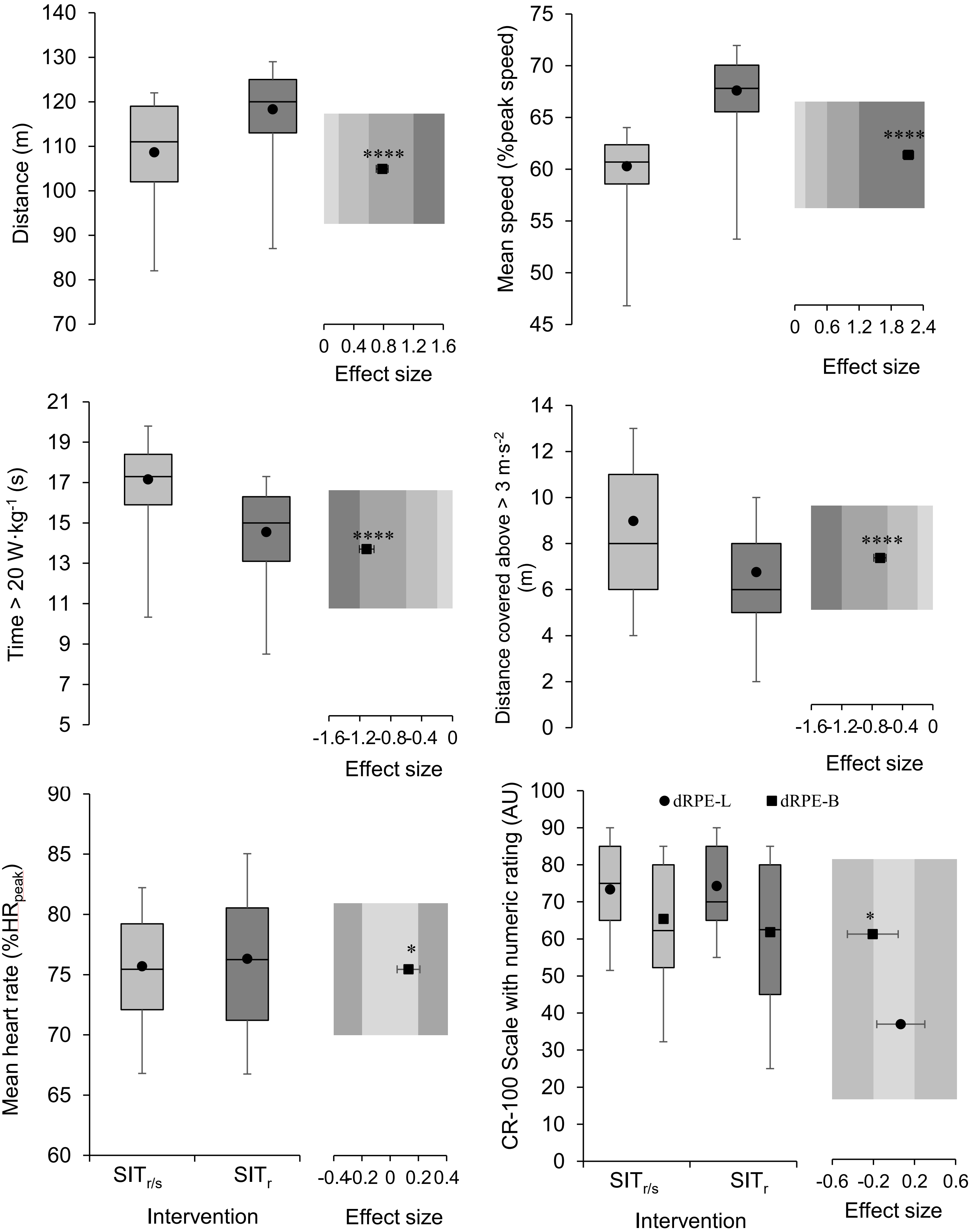

Figure 22. Between-group differences in internal, external and perceptual responses to the $SIT_{r/s}$ and SIT_r interventions. The whiskers-box plots represent the 25th-75th percentile of results inside the box; the median is indicated by the horizontal line across the box and the mean by a solid black circle. The whiskers on each box represent the 5th-95th percentile of results. * *possibly* (25-75%), ** *likely* (75-95%), *** *very likely* (95-99.5), **** *most likely* (> 99.5%).

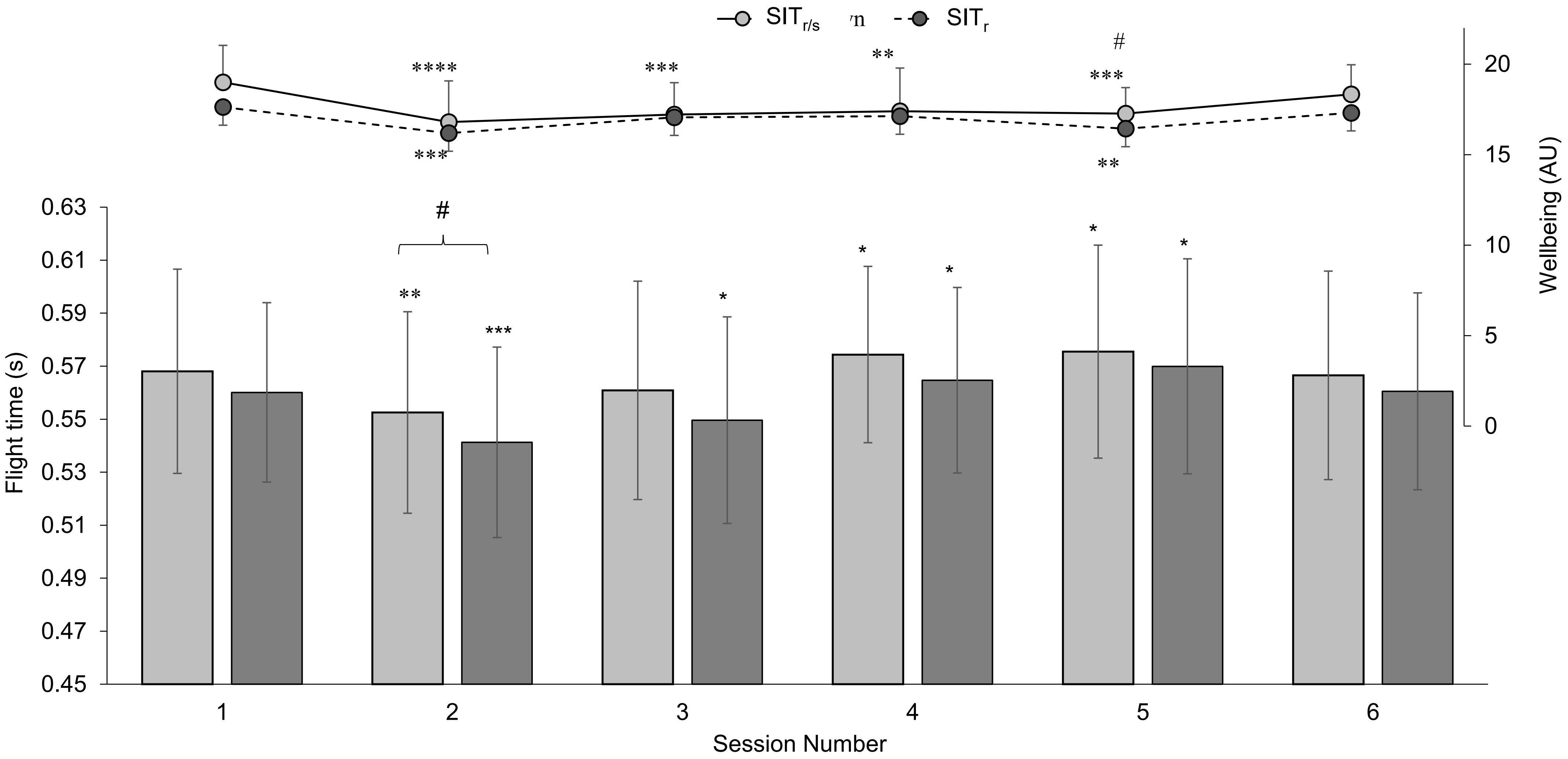

Figure 23. Mean ± SD daily perceived wellbeing (circles) and countermovement flight time (bars) for the $SIT_{r/s}$ (light grey) and SIT_r (dark grey). ** *likely* (75-95%), *** *very likely* (95-99.5%) **** *most likely* (>99.5%) within-group change. # possible between-group difference.

8.4. Discussion

Given the reductions observed in some physical characteristics in the last quarter of the competitive season (Chapter 7), this study investigated the effects of two sprint interval interventions on the physical characteristics, wellbeing and neuromuscular function of academy rugby league players when conducted in-season. In doing so, the study sought to determine if the RLAP battery is sensitive enough to detect changes in physical characteristics after real-world training interventions when considered in the context of its reliability as described in Chapter 3. The internal, external and perceptual response to training indicated that both interventions were very high-intensity training modalities; $SIT_{r/s}$ elicited a greater metabolic load, whilst the SIT_r group covered greater distance at a higher mean speed. Both interventions were effective for eliciting positive changes in the physical characteristics and the change in prone Yo-Yo IR1 for the $SIT_{r/s}$ met the required change with results from SIT_r almost achieving this. The interventions were also effective for improving HRR and the submaximal responses to the prone Yo-Yo IR1. Between-group analysis favoured the $SIT_{r/s}$ for some characteristics despite similar absolute training loads across the intervention. The overall mean change in wellbeing and neuromuscular function were unclear.

The within-group mean improvements in sprint, CMJ, change of direction and medicine ball throw performance contrast previous observations demonstrating no clear effect of 3 to 7 weeks of SIT on power-, force- and speed-based actions.[35,158] Results do, however, agree with studies that have used repeated sprint training with mean improvements in all outcome measures,[157,237] though the observed mean change for 10 m, 20 m, CMJ, change of direction and medicine ball throw in this study were less than the required change noted in Chapter 3. As such, this suggests these tests in the RLAP battery might not be sensitivity to small changes following a period of SIT training. Nonetheless, the small to moderate within-group changes might be explained by muscular adaptation, including an increase in substrate (i.e. phosphocreatine), enzymatic activity[87,158] and alteration of contractile properties,[215] as well as potential neural adaptations (i.e. fibre recruitment, firing rate, motor unit synchronisation, recruitment of the gluteal muscle group).[157,237] Results indicate that exposure to maximal speed and emphasis on accelerated running, particularly during $SIT_{r/s}$, constitutes an important element for improving power-, force, and speed-based actions,[157] and likely explains the trivial to small between-group differences in favour of $SIT_{r/s}$ for 10 m sprint, CMJ, change of direction and medicine ball throw performance. Practitioners might consider including sport-specific actions in conjunction with SIT to maximise adaptation in power-, force- and speed-orientated characteristics in rugby league players.

Both interventions appeared equally effective for eliciting improvements in prone Yo-Yo IR1 performance with the mean change in $SIT_{r/s}$ (120 m) and SIT_r (112 m) being similar to the required change of 120 m noted in Chapter 3. Such findings suggest the prone Yo-Yo IR1 might be sensitive to changes elicited through a SIT intervention and are important given its relationship with the internal and external responses to simulated match-play (Chapter 5). These results reaffirm the small to large improvements in Yo-Yo IR1 performance after SIT and/or repeated sprint training in team-sport athletes.[84,183,237] Although not directly measured, the improvement in total distance covered is potentially explained by several central and peripheral adaptations that promote oxygen delivery and uptake as well as mitochondrial enzyme activity, protein content (i.e. monocarboxylate transport 1 and Na^+/K^+ pump subunit β_1), muscle lactate and H^+ regulation capacity and phosphocreatine and muscle glycogen stores, amongst others; all of which likely delayed the onset of fatigue during the prone Yo-Yo IR1.[87,182] Two weeks of high intensity training might also have increased exercise-induced pain tolerance that contributed to participants willingly extending their running time at maximal intensity during the second Yo-Yo IR1. For example, O'Leary et al.[207] demonstrated that 6 weeks of high-intensity exercise increased pain tolerance through greater central tolerance of nociception and was positively associated with time to exhaustion during a cycling test. Further work is required to elucidate the mechanisms that contribute to improve high intensity intermittent running performance after short-term sprint interval training interventions in team sport athletes.

Improvements in sub-maximal HR_{mean} and HRR in both $SIT_{r/s}$ and SIT_r are associated with improvements in cardiorespiratory fitness[36] including increases in stroke volume, cardiac output, blood volume[182] and reductions in sympathetic activity.[36] The mean change in HRR was similar to Buchheit et al.[36] after 10 weeks of high-intensity training in adolescent soccer players (60.0 ± 12.2 *cf.* 75.6 ± 13.6 $b \cdot min^{-1}$). Such findings indicate that both interventions induced an increase in parasympathetic reactivation and sympathetic withdrawal at exercise cessation.[36] Sub-maximal responses during the prone Yo-Yo IR1 also suggest that $SIT_{r/s}$ appears to have enhanced the neuromuscular adaptation that might explain the trivial to moderate between-group differences in the time spent at HMP and small between-group differences in distance covered above 3 $m \cdot s^{-2}$. From an applied perspective, this finding might encourage practitioners and coaches in rugby league to incorporate such actions within conditioning practices in an attempt to develop rugby players' ability to get up from the floor quickly, which in turn might reduce the external loads (i.e. acceleratory distance) placed on players during intermittent running.

Whilst our results support the notion that $SIT_{r/s}$ and SIT_r are effective training modalities for promoting the physical characteristics of rugby league players, a key purpose of this study was to explore the efficacy of this during the competitive season. Our results for wellbeing and neuromuscular function revealed likely to most likely reductions during session two, which reflects the introduction of novel maximal-intensity activity during a period where such training is typically limited.[95] However, it is important to note that the mean change in wellbeing and neuromuscular function were unclear between sessions 1 to 6, indicating that 2-weeks sprint interval training can be incorporated in-season without residual neuromuscular and perceptual fatigue.

This study builds on the existing literature and addresses a number of the limitations previously noted. For example, a detailed insight into the accumulated training load across the two weeks enables practitioners to understand the required exercise dose to elicit the improvements observed. The intervention was also included within each team's current training schedule with only field-based conditioning replaced by $SIT_{r/s}$ or SIT_r, increasing the ecological validity of this study. Furthermore, the study included measures of neuromuscular function and wellbeing throughout the training period that have not been considered previously. There are, however, several limitations that warrant acknowledgement. The study did not include a control group that completed only their normal training, meaning the effectiveness of $SIT_{r/s}$ and SIT_r beyond their usual conditioning remains unknown. Whilst it is possible that the club's training might have resulted in improvement over this period, it is important to note the negative change observed in Chapter 7 from the mid-season period until the end of season. As such, positive changes over this period are unlikely. The researcher was also unable to determine whether the change in physical characteristics positively influenced a player's match performance. However, given the relationship between the prone Yo-Yo IR1 and simulated match-play (Chapter 5), it is anticipated both interventions would offer several benefits to enhance match performance. It is also acknowledged that, when taking into account the reliability of the outcome measures, the sample size required for adequate precision in change of mean is likely greater than that used in this study and potentially at risk of type I or type II errors. Finally, the intervention coincided with a mid-season period of no fixtures for the two clubs, so whether $SIT_{r/s}$ and SIT_r are suitable when combined with weekly matches is unclear.

8.5. Conclusions and practical applications

Between-group analysis supports the inclusion of sport-specific actions in the attempt to increase the systemic loads of SIT training and promote greater adaptation for physical characteristics and sub-maximal responses to intermittent running. Such findings should encourage practitioners to consider including sport-specific, metabolically demanding actions such as the up/down action used in this study within current training practices in rugby league. Furthermore, the within-group changes indicate that the RLAP battery is has sufficient sensitivity for some (i.e. prone Yo-Yo IR1) but not all (i.e. 10 m sprint) physical characteristics. Such findings do, to some degree, support the utility of this battery for assessing changes in physical characteristics, though consideration for type of training is required where little focus was placed on mechanical properties of sprinting, whole-body power development or change of direction ability during the SIT intervention. In addition, this study highlights how repeated shuttle sprinting can provide a stimulus that reduced the acceleratory responses to rugby-specific prolonged high-intensity intermittent running and therefore emphasis placed on accelerating, decelerating and changing direction should be incorporated into future training practices. Finally, these results also revealed that incorporating SIT training within the competitive season is feasible without compromising athlete wellbeing or neuromuscular function, and should be considered by practitioners, particularly during the latter stages where some physical characteristics might deteriorate as reported in Chapter 7.

In conclusion, $SIT_{r/s}$, and to a lesser extent SIT_{r}, are effective in-season micro-dosing strategies for improving some physical characteristics important in rugby league that could be detected using the RLAP battery. Furthermore, the inclusion of SIT during the season and when combined with players' normal training routine did not elicit detrimental reductions in wellbeing and neuromuscular function. In all, $SIT_{r/s}$ and SIT_{r} are effective training modalities that can be used to promote the physical characteristics of elite academy rugby league players' in-season.

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Chapter 9
Conclusions

9.1 Key findings

9.1.1. The application of the RLAP battery for rugby league

This project sought to determine the utility of the RLAP battery that was adapted from the RFL's SPARQ battery for assessing the anthropometric and physical characteristics of UK-based rugby league players. The battery of tests originally proposed by the RFL was designed to assess a number of characteristics in a user-friendly manner, able to be continued beyond the project and be efficient to complete with large playing groups. The results of Chapter 3 supported the inclusion of all tests except the CMJ using an arm swing, where reliability was poorer than without an arm swing and both provide an indication of lower-body power. As noted in Chapter 3 and 4, the testing procedures took approximately 75 minutes to complete. The efficiency of the RLAP battery as well as the minimal technical equipment required was a key factor in the implementation of the battery across Chapters 3, 4, 7 and 8. Chapter 7 and 8 required players to complete the RLAP battery during the competitive season, where testing is often considered impractical due to logistical challenges, congested fixtures, limited recovery between matches and increases in acute training loads.[234]

The suitability of the RLAP for assessing the anthropometric and physical characteristics of rugby league players was demonstrated throughout the thesis whereby a range of age groups were tested at professional (Chapter 3, 4, 5, 7 and 8) and amateur standards (Chapter 5 and 6). For example, Chapter 4 highlights that the RLAP battery is suitable for those categorised as youth, academy and senior players without modification. In addressing one of the RFL's aims, this thesis presents a large data set that enables clubs to have access to position-specific normative data at youth, academy and senior standards. The collection of this normative data allows practitioners to compared players against position- and group-specific norms to make informed decisions around the development needs of players. An example of this is presented in Appendix 10.

The continued application of the RLAP battery by individual clubs and the sports NGB can serve a number of important functions. For the clubs, the battery provided a range of simple tests that can be implemented within key phases of the season in an efficient manner to provide insight into the players' training status or more importantly, the development of a player over time. A single assessment of a player is known to have little practical use and therefore testing batteries that are excessive, and consequently, only used during preseason might have limited usefulness. In contrast, this thesis demonstrates how club practitioners can use the RLAP battery, measurement properties, and normative data regularly (i.e. 4 times per season as in Chapter 7) to not only support player identification and development but to assess longitudinal changes in players and evaluate the effectiveness of training modalities. The emphasis placed on evaluating training modalities such as that in Chapter 8, might be a more appropriate use of RLAP that appeals to all involved in the development of players, including sport scientists, medical staff and skills coaches as this will potential benefit rugby league performance rather than simply serving to highlight deficiencies of a player that might already be known.[190] That said, highlighting strengths and weaknesses of an individual against comparable and representative data such as that in Chapter 4 can aid in the development of players and should be used in conjunction with the coach's needs of an individual to direct the focus on training and allow for a more individualised and performance-orientated approach.[190]

9.1.2. Calculating and using appropriate reliability statistics to interpret the magnitude of change or difference in measures of physical characteristics.

The reliability of any performance test used to assess the anthropometric and physical characteristics must be within acceptable limits in order to accurately determine a meaningful change.[7,153] As noted by Hopkins[153] in his review, reliability studies that include a sample size of ≥ 50 participants across a minimum of three trials are rare. However, a sample size of 50 across three repeated trials conducted in the same environment, using the same equipment and carried out by the same researcher gives the lowest confidence limits for the ratio of the TE and adequate precision for the estimate of typical error.[153] In addition to providing a true measure of reliability for each test of the battery, these results also revealed that amongst academy players, habituation was not required. The reliability statistics used in Chapter 3 included checking for any change in the mean values as well as the TE, ICC and SWC. As recommended by Haugen and Buchheit,[135] the TE and SWC were combined to give a required change that can be used to determine a meaningful change or difference.

Throughout the thesis, the reliability of the RLAP battery was acknowledged and used when interpreting the results of empirical work. For example, in Chapter 7 the statistical analysis enabled inferences about what a change in one physical characteristic might have on others. Using the 2.9 cm required change for the CMJ in Chapter 2, it was likely that a 6.4 m increase in prone Yo-Yo IR1 performance would be observed. Furthermore, the required change was used in Chapter 8 and Appendix 13 when making inferences about the change in performance after a period of training. In Chapter 8, the mean change in prone Yo-Yo IR1 was comparable to the required change after $SIT_{r/s}$, whilst in Appendix 13 mean change in CMJ and prone Yo-Yo IR1 exceeded the required change after 12 weeks of pre-season training. In all, this thesis highlights how the reliability of performance tests within a battery is important and demonstrates how this information can be used to make inferences regarding the change in performance (Chapter 7, 8 and Appendix 13).

9.1.3. The importance of sport-specific, metabolically demanding actions.

Incorporating sport-specific actions such as collisions, wrestles, accelerating, decelerating and changing direction in current training and testing practices for rugby league players have been advocated due the greater loads imposed on players and closer reflection of match-play.[67,166,170,171,204] Whilst the inclusion of one or more of the aforementioned actions have been incorporated in simulated match-play[204,205,236] and tests for repeated high-intensity efforts,[164] their inclusion in tests of high-intensity intermittent running was lacking. Furthermore, Gabbett and Seibold[92] highlighted the lack of association between the Yo-Yo IR1 and match-play characteristics, with the lack of a sport-specific action explaining this finding. Throughout this thesis, it was consistently demonstrated that the inclusion of sport-specific actions in a test of high-intensity intermittent running is useful when assessing rugby league players. In Chapter 4, the prone Yo-Yo IR1 possessed discriminant validity, confirming that senior players are better able to perform repeated intermittent running incorporating getting up from the floor, accelerating, changing direction and recovering between shuttles when compared to youth and academy players, despite their greater body mass. Such actions are vital physical performance characteristics that are better evaluated when using the prone Yo-Yo IR1 compared to the traditional Yo-Yo IR1 test. The 24% unexplained variance in prone Yo-Yo IR1 performance not accounted for from Yo-Yo IR1 distance reveals that the modified test assesses unique characteristics not captured in the traditional test (Chapter 6). Indeed, the inclusion of an up-and-down action into the Yo-Yo IR1 improved its association with external (e.g. time above HMP), internal (e.g. %HR_{peak}) and perceptual (i.e. RPE) loads associated with simulated match-play when compared to the Yo-Yo IR1 (Chapter 5). The prone Yo-Yo IR1 distance was also positively associated with league position (Chapter 7) and it is therefore recommended that practitioners in rugby league consider incorporating sport-specific actions when assessing and training the physical characteristics of players.

Results in Chapters 6 and 8 revealed that including the up-and-down action increases the emphasis on highly metabolically demanding actions such as accelerated running at sub-maximal and maximal intensities during the prone Yo-Yo IR1 and sprint interval training. Furthermore, Chapter 8 demonstrates that incorporating a high volume of accelerated running using a shuttle-based protocol elicits high physiological loads[4,71] and appears important for explaining the overall improvement in prone Yo-Yo IR1 performance as well as the sub-maximal internal and external loads during the same test. Indeed, these results support the inclusion of sport-specific actions in both assessments of physical characteristics and training practices when working with rugby league players.

9.1.4. Understanding the interaction between anthropometric and physical characteristics.

The interaction between anthropometric and physical characteristics, as well as other contextual factors (i.e. season phase), is important for those working with rugby league players, particularly youth or academy athletes. The results in Chapter 6 revealed a small negative correlation between body mass and prone Yo-Yo IR1 that was reaffirmed in Chapter 7. The small association between prone Yo-Yo IR1 and body mass likely reflects the homogeneity of the samples used in Chapter 6 and 7, and it is anticipated that a player's body mass would negatively impact their prone Yo-Yo IR1 performance. This observation potentially disadvantages heavier players[63] such as props (Chapter 4), though is not explained by greater skinfold thickness (Chapter 7). The negative association between body mass and other characteristics, such as 10 m, 20 m and change of direction time and CMJ height, supports the notion that careful consideration is required by strength and conditioning coaches in rugby league when planning the long-term development of young players. For example, by increasing a player's mass to optimise on-field performance[265] there is a potential 'trade off' with decrements in speed, change of direction and jump height. Skinfold thickness was not associated with any physical characteristics but was influenced by playing position and season phase. Furthermore, understanding the association between characteristics has received minimal consideration[69,220] despite its importance for talent development and the implications this might have for training. The results in Chapter 7 reported some of the associations between anthropometric and physical characteristics, and Chapter 8 revealed that sprint interval training, which aimed to promote prone Yo-Yo IR1 performance, appeared to positively influence all physical characteristics. This thesis offers some insight into the interaction between anthropometric and physical characteristics and suggests that development of specific characteristics might have positive or negative effects on others essential for rugby league progression and performance.

9.2. Limitations

9.2.1. Participant training status

Whilst the research in this thesis is the first to investigate the anthropometric and physical characteristics of UK-based players across 12 professional clubs, it is important to acknowledge the limited use of senior professional players. Chapter 4 reports on the anthropometric and physical characteristics of senior professional players albeit, the sample was limited to 132 players across five clubs. Therefore, the data presented is not truly representative of all senior professional players across the league. The thesis largely focused on academy players due to accessibility and support from academy staff, suggesting caution when extrapolating the findings in Chapter 5, 7 and 8 to senior professional players. For example, whether the same contextual factors explored in Chapter 7 affect the anthropometric and physical characteristics of senior players remains unknown. Furthermore, incorporating the sprint interval training within the competitive Super League season is likely to pose several challenges for practitioners and researchers during periods of high fixture demands, which are more regular when compared to the academy competition. However, using an alternative mode of SIT such as cycling protocol or using this at an individual level throughout the season might be a possible strategy that is viewed more favourably by those working with senior players. Furthermore, as senior players outperform academy players across a number of key physical characteristics (Chapter 4), potentially due to training experience,[19] it is possible that a greater training stimulus might be required to elicit similar improvements to that observed in Chapter 8.

9.2.2. Relationship between physical characteristics and match-play

The concurrent validity of any new tests is important to ensure the development of characteristics that influence on-field performance.[59,60,215,229] In rugby league, limited research has investigated the concurrent validity against match-play due to a number of factors. Firstly, it is important to account for the high match-to-match variability in performance metrics used in rugby league (i.e. high-speed running = 14.6%).[178] Given these are likely to alter the association between physical characteristics and measures of external load, attempts should be made to control for this using a large number of observations (for example, 1269 observations in soccer referees)[269] across multiple clubs to ensure a 'true' reflection of match performance.[178] Finally, before such analysis can be conducted in rugby league, it is essential that the external loads are clearly defined with descriptors that are agreed upon by researchers and practitioners. For example, Hausler et al.[139] reported considerable heterogeneity (I^2 > 0.75%) in external loads used, which, in part, could be explained by the large range of speed thresholds used across studies. As such, the use of a simulation protocol was favoured in Chapter 5, thus allowing determination of the association between rugby-specific intermittent running and responses to the RLMSP-i without interference. Whilst this finding supports the use of the prone Yo-Yo IR1, its association with match-play loads requires further research.

9.2.3. The lack of a field-based measure of strength

The battery was used throughout this thesis did not include a measure of strength (i.e. peak force, maximum load), despite its association with match-play,[92] career success,[246] tackling technique[114] and injury risk.[185] The standardised battery was required to meet a number of criteria that resulted in the omission of a measure of strength, including being easily transportable, efficient, simple as well as suitable for athletes across all playing ages and standards. As revealed in the systematic review, no field-based measures of lower- or upper-body strength have been reported in the rugby league literature, whilst a single study included a measure of whole-body strength (i.e. isometric mid-thigh using a dynamometer). However, the criterion validity of this test was not explored, and it was unknown if this provides an accurate measure of strength in rugby league players. Due to this limitation, a field-based measure of whole-body strength using a portable isometric mid-thigh pull dynamometer has since been validated in rugby league athletes (Appendix 12) that is now included within the RLAP battery being used the RFL and professional clubs. This work is not presented as part of the thesis but was recommended as an additional measure alongside those presented herein and has since been incorporated.

9.2.4. Testing conditions

The researcher organised and conducted all measurements for each study using the same equipment. However, as data collection was largely conducted in an applied environment, several factors were difficult to control. For example, one club's players were consistently tested on an indoor rubber surface whereas all others included in this thesis were tested on artificial 3G turf. The researcher was also unable to control who was present during the performance testing. In all instances the researcher led the session whilst the academy head coach, strength and conditioning coach and physiotherapist were present. The data in Appendix 14 demonstrates that the addition of spectators, particularly those affiliated with the senior team, had a positive effect on linear acceleration and sprint times, CMJ and prone Yo-Yo IR1 performance (Figure 1 in Appendix 14). Moreover, it was revealed that the effect of spectators was not systematic with some individual performances being impaired (Figure 2 in Appendix 14). As such, it is possible that the observed scores across all studies were affected by the presence of additional spectators at each club for data presented in Chapters 3, 4, 5, and 7. However, the presence of senior team staff was uncommon and the magnitude of the differences in scores was likely lower than the required change reported in Chapter 3.

9.3. Future directions

9.3.1 Continuation of the RLAP battery by RFL or clubs

This project has utilised the RLAP battery for the assessment of anthropometric and physical characteristics of rugby league players. Whilst this study provides a large database of normative results for researchers and practitioners in rugby league to use, continuing to add to this database would be worthwhile as would using this battery with other rugby league populations such as female players or younger age-groups. Such information would provide standardised information on a range of players across multiple playing groups as well as allowing any changes in anthropometric and physical characteristics to be detected and understood with reference to the game. The sport's governing body might consider implementing this battery within the accreditation scheme for youth, academy and women's rugby league. This information would continue to provide comparative data that can be used to help inform talent identification and development as well as training practices across the game.

9.3.2 Determining predictors of success

Using a cross-sectional design, Chapter 4 indicates that the physical characteristics of rugby league players play an important role in their progression from youth to senior status. Using a longitudinal design, future research might seek to track the development and progression of the youth and academy athletes who participated in this project thus, establishing which characteristics best determine progression into professional and/or international squads. For example, in soccer, performance on the Yo-Yo IR1 has been reported to an important predictor of career progression in elite youth female players with the probability for those scoring above 2040 m being 64.7%.[64] In addition to this, further work is required to understand the complex interaction between characteristics and how manipulating these can alter a player's chances of successful progression or selection. For example, Chapter 7 demonstrated that body mass was negatively associated with a number of key characteristics that might hinder a player's chance of progression due to poorer speed, lower-body power and rugby-specific intermittent running. Research is required to determine if the characteristics assessed are related to key performance indicators associated with actual match-play, such as repeated high-intensity efforts, high-speed running and tackling technique,[91] whilst controlling for match-to-match variability.[177] This thesis highlighted that performance in the prone Yo-Yo IR1 appears important for rugby league players and therefore greater understanding of the contributing factors to successful prone Yo-Yo IR1 performance is required to ensure training specificity. For example, an athlete's performance could be influence by their poor ability to get up from the prone position, generate ground reaction force during the initial acceleration of the shuttle or decelerate and change direction efficiently. Finally, the results presented in Chapter 8 revealed that several performance characteristics were impaired between the mid- and end-of-season phases. Whilst currently unknown, it is possible that such observations are associated with reductions in training loads during the season[95] and a detraining effect during the latter stages of a season. As such, further work might seek to determine the factors associated with a reduction in physical characteristics in academy players and seek to determine if similar patterns are reported by senior players. Indeed, if such reductions are associated with reduced training intensity, volume or frequency, research might seek to understand the efficacy of training modalities to promote or maintain the characteristics of athletes, such as small-sided games, SIT, high-intensity training and technical drills.

9.3.3 Incorporating coaches, skills and other attributes in the assessment of anthropometric and physical characteristics.

It is widely acknowledged that the assessment of physical characteristics plays an important role in rugby league. However, it remains that the practices of testing and interpreting the data collected is largely done by the strength and conditioning coaches with minimal input from skill coaches. In a recent study, Jones et al.[174] incorporated coaches' ratings of importance within the interpretation of three players' physical profiles. Using the z-score method, this study demonstrated how the degree of importance coaches place on specific characteristics can drastically alter the emphasis placed during training. For instance, using the example in Appendix 10, one might suggest that greater whole-body power training is needed to enhance medicine ball throw performance. However, if this is deemed less important by the coach than linear speed and change of direction ability, then emphasis on developing whole-body power might not be necessary. Further research is required to determine the suitability and application of coaches' ratings in the interpretation of anthropometric and physical characteristics, while understanding a coach's rationale for rating characteristics would be useful for those working in applied sport in order to focus resources.

The assessment of technical skills in rugby league has received greater interest in recent years, though remains infrequently used within applied practice. Chiwaridzo, Ferguson and Smits-Engelsman[42] reported seven rugby-specific skill tests in the literature that have been used to assess distinct skills including ground skills, passing, kicking, catching, tackling, draw and passing, and pattern recall. For the most part, rugby union players were used with only one study including rugby league players,[104] and therefore, further work is required to develop sport-specific skills that meet the criteria outlined in the systematic review when developing a new test. In addition, further work is required to understand the psychological and behavioural factors that are associated within talent identification and development.[212] Tredrea et al.[257] noted small differences between selected and non-selected players for a range of psychological attributes. Similarly, Golby and Sheard[131] reported higher total mental toughness scores in international players (171.17 ± 17.77 AU) compared to Super League (166.68 ± 16.68 AU) and Division 1 players (161.09 ± 19.25 AU). The authors also noted that commitment and challenge, as measures of hardiness, possessed discriminant validity with an accuracy of 81%. These findings suggest incorporating measures of hardiness and toughness into a battery might provide useful information for those involved in athlete education, identification and development.

9.4. Conclusion and practical implications

This thesis sought to evaluate the utility of the RLAP battery for assessing the anthropometric and physical characteristics of UK-based rugby league players. The battery is inexpensive, efficient and requires minimal technical expertise or equipment, allowing researchers and practitioners to use the procedures outlined herein to evaluate their own players. The results within this thesis also highlight that the battery is reliable and can discriminate between playing standards (Chapter 3 and 4). Furthermore, the results presented in Chapters 3, 4 and 7 should be used by practitioners as normative data on UK-based rugby league players though consideration for the contextual factors highlighted in Chapter 7 is required. For example, when comparing a youth or academy player to the normative data set, it is essential to consider the seasonal phase, age-group, their intended playing position and the characteristic desired by the senior coaches before comparing and making any recommendations for training or progression. This research also provides a rugby-specific Yo-Yo IR1 test that is reliable, valid and sensitive to changes following a low-volume sprint interval training intervention. The increased emphasis placed on metabolically demanding actions (i.e. accelerating, getting up from the floor) during the prone Yo-Yo IR1 (Chapter 6) improved its relationship with responses during simulated match-play (Chapter 5). Furthermore, when the same up-and-down action was incorporated into a sprint interval training intervention, greater improvement in sub-maximal loads and total distance during the prone Yo-Yo IR1 were observed, supporting the inclusion of such an action within training practice in rugby league (Chapter 8).

Overall, this research has adapted an existing battery of tests provided by the Rugby Football League named the RLAP battery. The empirical work presented in this thesis supports the utility of the RLAP battery for assessing youth, academy and senior rugby league players with a view of understanding players' physical characteristics, supporting talent development decisions, determining changes over time and/or evaluating the effectives of training practices. Collectively, the results support the

RFL's decision to continue to implement the battery with youth, academy and senior players in the UK beyond the completion of this body of work.

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Appendices

Appendix 1. Example participant information sheet

Participant Information Sheet

Title of Project: The reliability of the Rugby Football League fitness profiling battery in elite youth players

Name of Researcher: Nicholas Dobbin

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. If there is anything that is not clear or if you would like more information please contact the lead researcher. Take time to decide whether or not you wish to take part.

Thank you for reading this.

What is the purpose of the study?
This research is being undertaken on elite youth Rugby League players. The aim of this project is to examine the reliability of a number of fitness and performance tests that make up the Rugby Football League's profiling battery.
The reliability of a test is essential as knowing this will enable the coach to detect worthwhile changes in performance.

Why have I been chosen?
You have been chosen because are currently registered with an elite Rugby League club and are currently competing at the youth and/or academy level. Also, you are free of any injuries that might negatively affect your ability to perform any performance tests

Do I have to take part?
It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect you in any way.

What will happen to me if I take part?
The testing procedures will require you to complete three trials of the Rugby Football League profiling battery over a two-to-three week period. Each visit will take place after a recovery day, and will require you to complete a series of measures, including: body mass, height, body fat percentage, 10 and 20 m sprint, a zigzag shuttle run, a power pass, vertical jump and Yo-Yo Intermittent Recovery Test. Each visit will take approximately 2 hours to complete.

What are the possible disadvantages and risks of taking part?
There will be some disruption to your usual training, but no major disadvantages or risks are foreseen in taking part in the study.

What are the possible benefits of taking part?
By taking part, you will be contributing to the development of a Rugby Football League profiling battery, which hopefully can form the basis for future profiling within the RFL and associated clubs.

What if something goes wrong?
If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Nicholas Avis, Executive Dean of the Faculty of Science and Engineering, University of Chester, Thornton Science Park, Pool Lane, Ince, Chester CH2 4NU 01244 513197

Will my taking part in the study be kept confidential?
All information that is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the research will have access to such information.

What will happen to the results of the research study?
The results will be written up into a thesis for the degree of Doctor of Philosophy (PhD) and might also be published in a peer-reviewed paper. The data will also be used to inform reports provided to the Rugby Football League on the utility of the testing battery. Individuals who participate will not be identified in any subsequent report or publication.

Who is organising the research?
The research is a collaboration between the Rugby Football League and the University of Chester. The research is conducted as part of a PhD in Exercise Physiology supervised by the Department of Sport and Exercise Sciences at the University of Chester.

Who may I contact for further information?
If you would like more information about the research before you decide whether or not you would be willing to take part, please contact:

Nicholas Dobbin
n.dobbin@chester.ac.uk
01244 513 465

Thank you for your interest in this research.

Appendix 2. Example informed consent form

University of Chester

Project title: The effects of a two-week sprint interval training programme with or without contact on physical qualities of rugby players

Lead researcher: Nick Dobbin

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without my legal rights being affected. ☐

3. I consent to any partially collected data that the researchers deem is useful for the above name study being used in anonymised form. ☐

4. I agree to take part in the above study. ☐

Name of Participant	Date	Signature

Lead researcher	Date	Signature

Appendix 3. Example pre-test health screening form

Project title: Examination of a modified Yo-Yo test to measure intermittent running performance in rugby league players

Researcher: Nicholas Dobbin

(Please note that this information will be confidential)

Name………………………………..… DOB…………………

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you are fit and healthy enough to participate in this laboratory practical/research project.

	Yes	No
1. Have you in the past suffered from a serious illness or accident. If Yes, please provide details.	☐	☐

…………………………………………………………………………………………………
…………………………………………………………………………………………………

	Yes	No
2. Have you consulted your doctor the last 6 months If Yes, please provide details	☐	☐

…………………………………………………………………………………………………
…………………………………………………………………………………………………

3. Do you suffer, or have you suffered from:

	Yes	*No*
Asthma	☐	☐
Type 1 Diabetes	☐	☐
Bronchitis	☐	☐
Type 2 Diabetes	☐	☐
High blood pressure	☐	☐

	Yes	No
4. Is there any history of heart disease in your family	☐	☐

	Yes	No
5. Are you suffering from any infectious skin diseases, sores, wounds, or blood infections i.e., Hepatitis B, HIV, etc.? If Yes, please provide brief details.	☐	☐

…………………………………………………………………………………………………
…………………………………………………………………………………………………

		Yes	No
6.	Are you currently taking any medication If Yes, please provide details.	☐	☐

…………………………………………………………………………………………………
…………………………………………………………………………………………………

		Yes	No
7.	Are you suffering from a disease that inhibits the sweating process	☐	☐

		Yes	No
8.	Is there anything to your knowledge that may prevent you from participating in the testing that has been outlined to you? If Yes, please provide details.	☐	☐

…………………………………………………………………………………………………
…………………………………………………………………………………………………

Your Recent Condition

	Yes	No
• Have you eaten in the last 2 hours? If Yes, please provide details	☐	☐

…………………………………………………………………………………………………

Evaluate your diet over the last two days. **Poor Average Good Excellent**

	Yes	No
• Have you consumed alcohol in the last 24hr?	☐	☐
• Have you had any kind of illness or infection in the last 2 weeks	☐	☐
• Have you exercised in the last 2 days?	☐	☐

If Yes, please describe below

…………………………………………………………………………………………
…………………………………………………………………………………………

Persons will not be permitted to take part in any experimental testing if they:-

- have a known history of medical disorders (i.e. hypertension, heart or lung disease)
- have a fever, suffer from fainting or dizzy spells
- are currently unable to train because of a joint or muscle injury
- have had any thermoregulatory disorder
- have gastrointestinal disorder

- have a history of infectious diseases (i.e. HIV or Hepatitis B)

My responses to the above questions are true to the best of my knowledge and I am assured that they will be held in the strictest confidence.

Name: (Participant)…………………………………………………………

Date:…………………..…

Signed (Participant): …………………………………………………..

Name: (Researcher)……………………………………………..……

Date:…………….……….

Signed (Researcher): …………………………………………………..

Appendix 4. Ethical approval letter for Chapter 3

Faculty of Science and Engineering
Research Ethics Committee

Nicholas Dobbin
9 Eastway,
Little Sutton,
Cheshire,
CH66 1SG

3rd November 2015

Dear Nicholas

Study title: The reliability of the Rugby League fitness profiling battery in elite youth players
FSE-REC reference: 019/15/ND/SES
Version number: 1

Thank you for sending your application to the Faculty of Science and Engineering Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Enclosed?	Appendix №	Version №	Date
FSE-REC application form	**Mandatory**		1	05/10/15
List of references	**Mandatory**	1	1	05/10/15
Brief C.V. for main researcher	**Mandatory**	2	1	05/10/15
Letter(s) of invitation to participants	**N**			
Participant Information Sheet(s) [PIS]	**Y**	3	1	05/10/15
Participant consent form(s)	**Y**	4	1	05/10/15
Information sheets / letters to people	**N**			
Written permission from	**Y**	5	1	05/10/15

relevant personnel (eg. to use facilities) if required				
Interview schedule(s) or topic guide(s) if required	**N**			
Questionnaire(s) for the study	**N**			
Copies of advertisement material(s) if required	**N**			
Risk Assessment form(s)	**Y**	6	1	05/10/15
Other documents *(Please specify below, as necessary)*	**N**			
Supervisors CV	**N**	On record		
Health Questionnaire	**Y**	7	1	05/10/15
Schematic of Zigzag shuttle	**Y**	8	1	05/10/15

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Helen Southall
Chair, Faculty of Science and Engineering Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FSE-REC Representative

Appendix 5. Ethical approval letter for Chapter 4 and 7

Faculty of Science and Engineering
Research Ethics Committee

Nicholas Dobbin
9 Eastway,
Little Sutton,
Cheshire,
CH66 1SG

8th December 2015

Dear Nicholas

Study title: The reliability of the Rugby League fitness profiling battery in elite youth players
FSE-REC reference: 019/15/ND/SES
Version number: 1

Further to your letter of 30th November 2015, I am writing to confirm that your request to amend your original research proposal including your updated documents and plans meet the necessary criteria for ethical approval.

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Helen Southall
Chair, Faculty of Science and Engineering Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FSE-REC Representative

Appendix 6. Ethical approval letter for Chapter 5 and 6

University of Chester

Nicholas Dobbin
9 Eastway,
Little Sutton,
Cheshire,
CH66 1SG

15th April 2016

Dear Nicholas,

Study title: Examination of a modified Yo-Yo test to measure intermittent running performance in rugby league players

FSE-REC reference: 036/16/ND/SES
Version number: 2

Thank you for sending your application to the Faculty of Science and Engineering Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Faculty of Science and Engineering Research Ethics Committee

Document	**Enclosed?**	**Appendix No**	**Version No**	**Date**
FSE-REC application form	**Mandatory**	N/A	2	15/03/16
List of references	**Mandatory**	1	2	08/02/16
Brief C.V. for main researcher	**Mandatory**	2	1	08/02/16
Letter(s) of invitation to participants	**N**	-	-	-
Participant Information Sheet(s) [PIS]	**Y**	3	2	15/03/16
Participant consent form(s)	**Y**	4	1	08/02/16
Information sheets / letters to people	**N**	-	-	-
Written permission from relevant personnel (e.g. to use facilities) if required	**N**	-	-	-
Interview schedule(s) or topic guide(s) if required	**N**	-	-	-
Questionnaire(s) for the study	**N**	-	-	-
Copies of advertisement material(s) if required	**N**	-	-	-
Risk Assessment form(s)	**Y**	5	1	08/02/16
Supervisors C.V.	**N**	On record	1	-
Health screening questionnaire	Y	6	1	08/02/16
Schematic representation of the modified Yo-Yo Test	**Y**	7	1	08/02/16

Rugby league match simulation protocol.	**Y**	8	1	08/02/16
NASA Task Load Index	**Y**	9	1	08/02/16

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project. Yours sincerely,

Helen Southall

Chair, Faculty of Science and Engineering Research Ethics Committee Enclosures:
Standard conditions of approval.
Cc. Supervisor/FSE-REC Representative

Appendix 7. Ethical approval letter for Chapter 8

Tuesday, 8th May 2018

Nicholas Dobbin
Tower 604
University of Chester
Parkgate Road
Chester
CH1 4BJ

Dear Nick,

Study title: The effects of a two-week sprint interval training programme with or without contact on physical qualities of rugby players.
FREC reference: 1413/18/CT/SES
Version number: 1

Thank you for sending your application to the Faculty of Medicine, Dentistry and Life Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	1	March 2018
Appendix 1 – List of References	1	March 2018
Appendix 2 – Summary CV for Lead Researcher		
Appendix 3 – Risk Assessment	1	March 2018
Appendix 4 – Participant Information Sheet [PIS]	2	April 2018
Appendix 5 – Participant Consent Form	1	March 2018
Appendix 6 – Written permission(s) from relevant personnel (eg. to use faculties)	1	March 2018
Appendix 7 – Health Screening Document	1	March 2018
Appendix 8 – Original approval for testing battery	1	March 2018
Appendix 9 – MDLS FREC approval for testing battery	1	March 2018
Appendix 10 – Ethics approval for the collision-based protocols	1	March 2018
Appendix 11 – Power calculation for sample size	1	March 2018
Appendix 12 – Schematic of the study design	1	March 2018
Appendix 13 – CV for assistant researcher	1	March 2018
Appendix 14 – Parental Consent Forms	1	March 2018

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the

Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project. Yours sincerely,

Professor Stephen Fallows

Deputy Chair, Faculty Research Ethics Committee Enclosures: Standard conditions of approval.
Cc. Supervisor/FREC Representative

Faculty of Medicine, Dentistry and Life Sciences Research Ethics Committee

frec@chester.ac.uk

Appendix 8. Figures accompanying systematic review

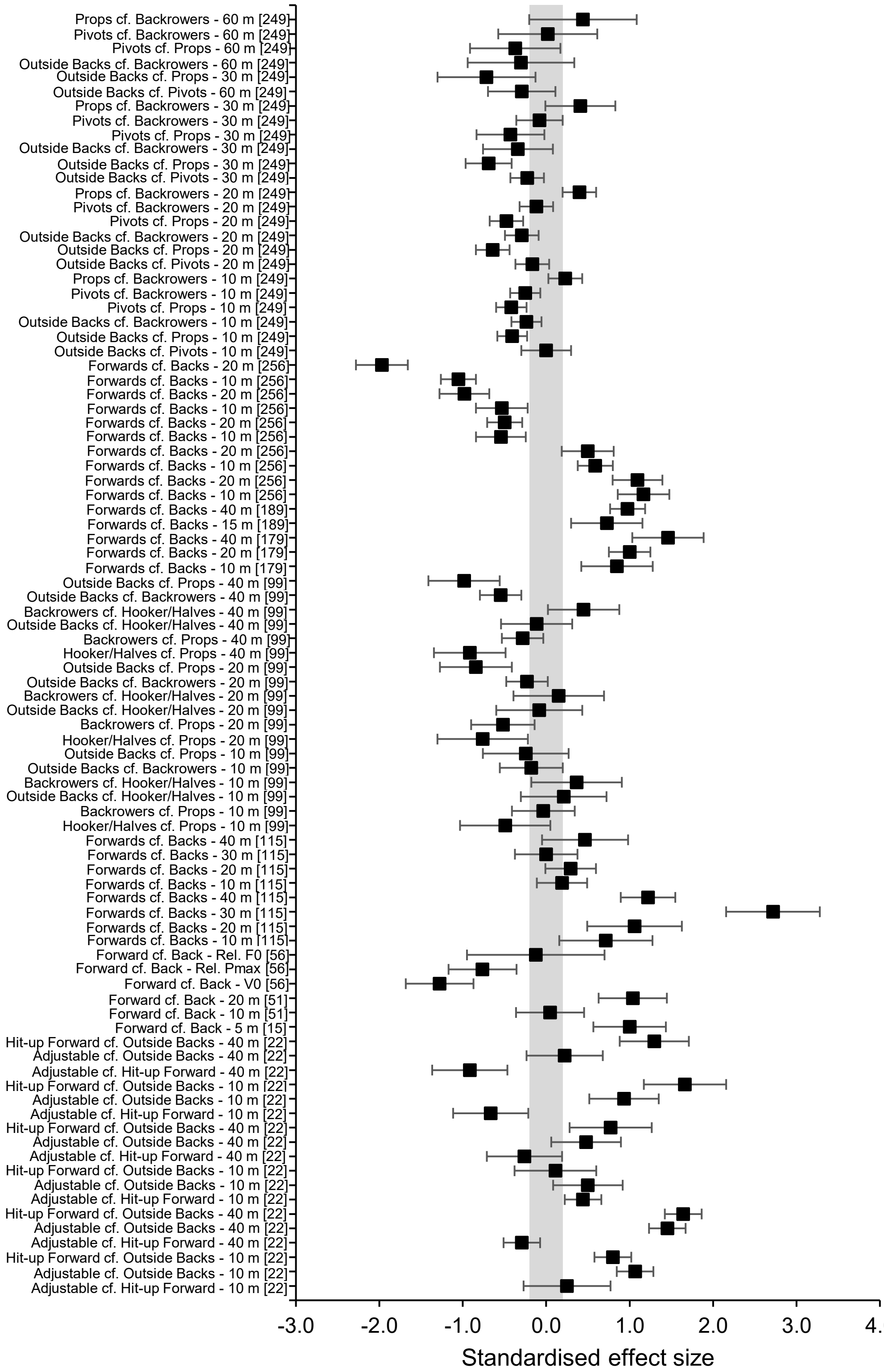


Figure 1. Standardised differences (±90% CI) in sprint and sprint properties between playing positions. Rel. F0 = optimal relative horizontal force. Pmax = maximum power. V0 = optimal velocity.

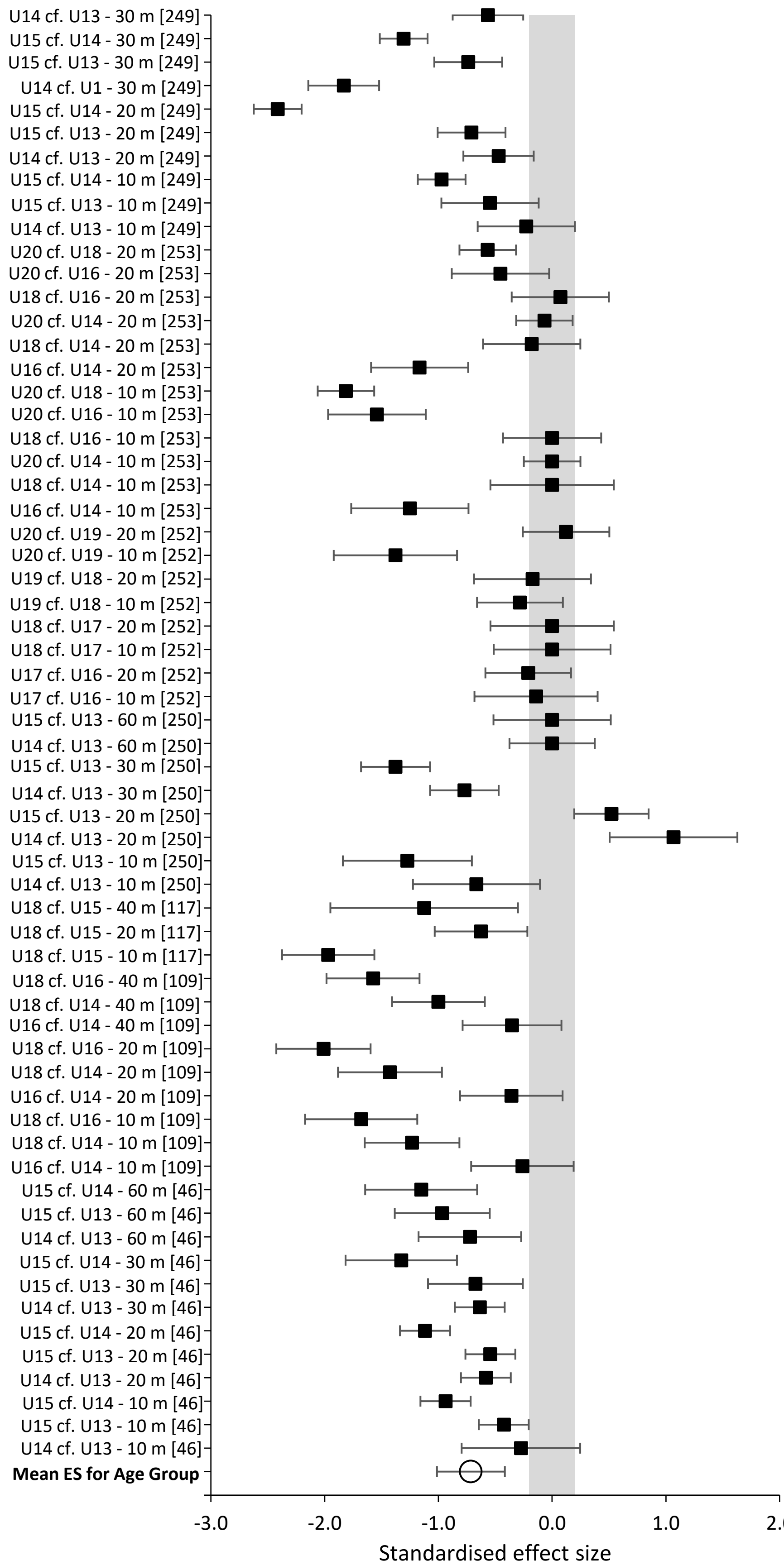


Figure 2. Standardised differences (±90% CI) in acceleration and sprint times with references to playing age. Open circle represents the mean effect size.

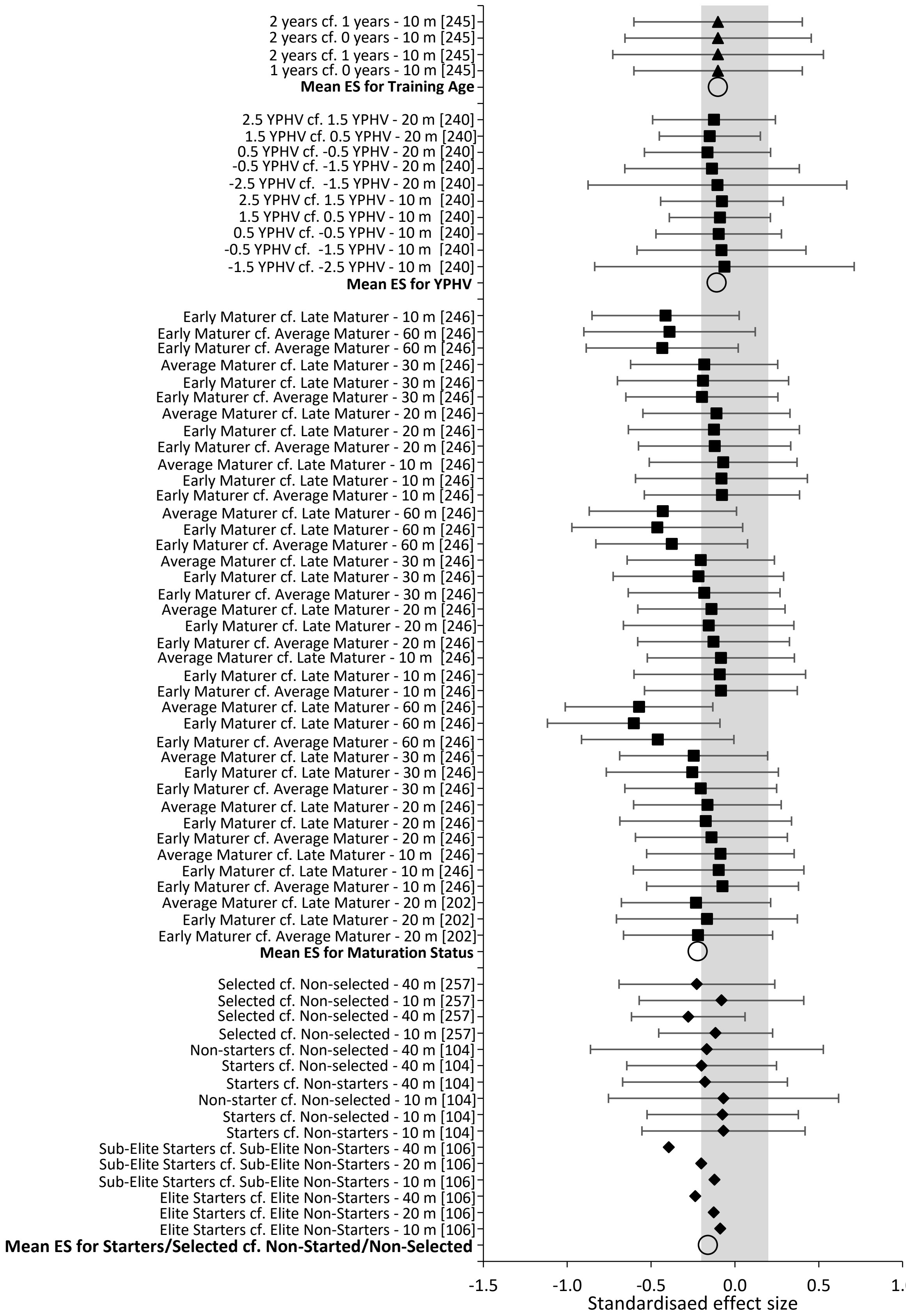


Figure 3. Standardised differences (±90% CI) in acceleration and sprint times between training years (triangles), maturation status (squares) and selected/non-selected (diamonds). YPHV = year at peak height velocity. Open circle represent mean effect size.

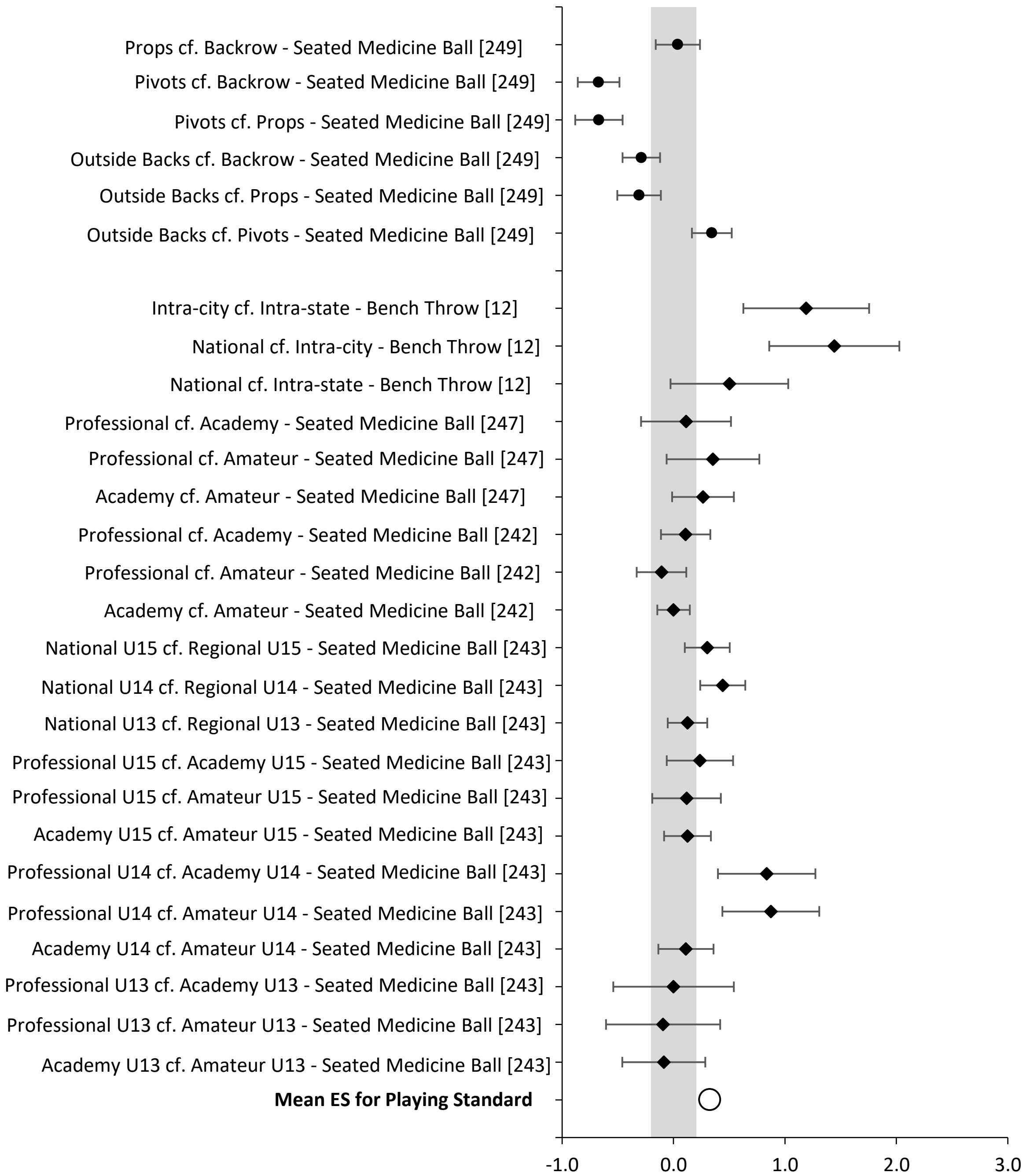


Figure 4. Standardised differences (±90% CI) in seated medicine ball throw between playing positions (circles) and playing standards (diamonds) for measures of upper-body muscle power. Q = quartile. YPHV = year at peak height velocity. Open circle represents the mean effect size.

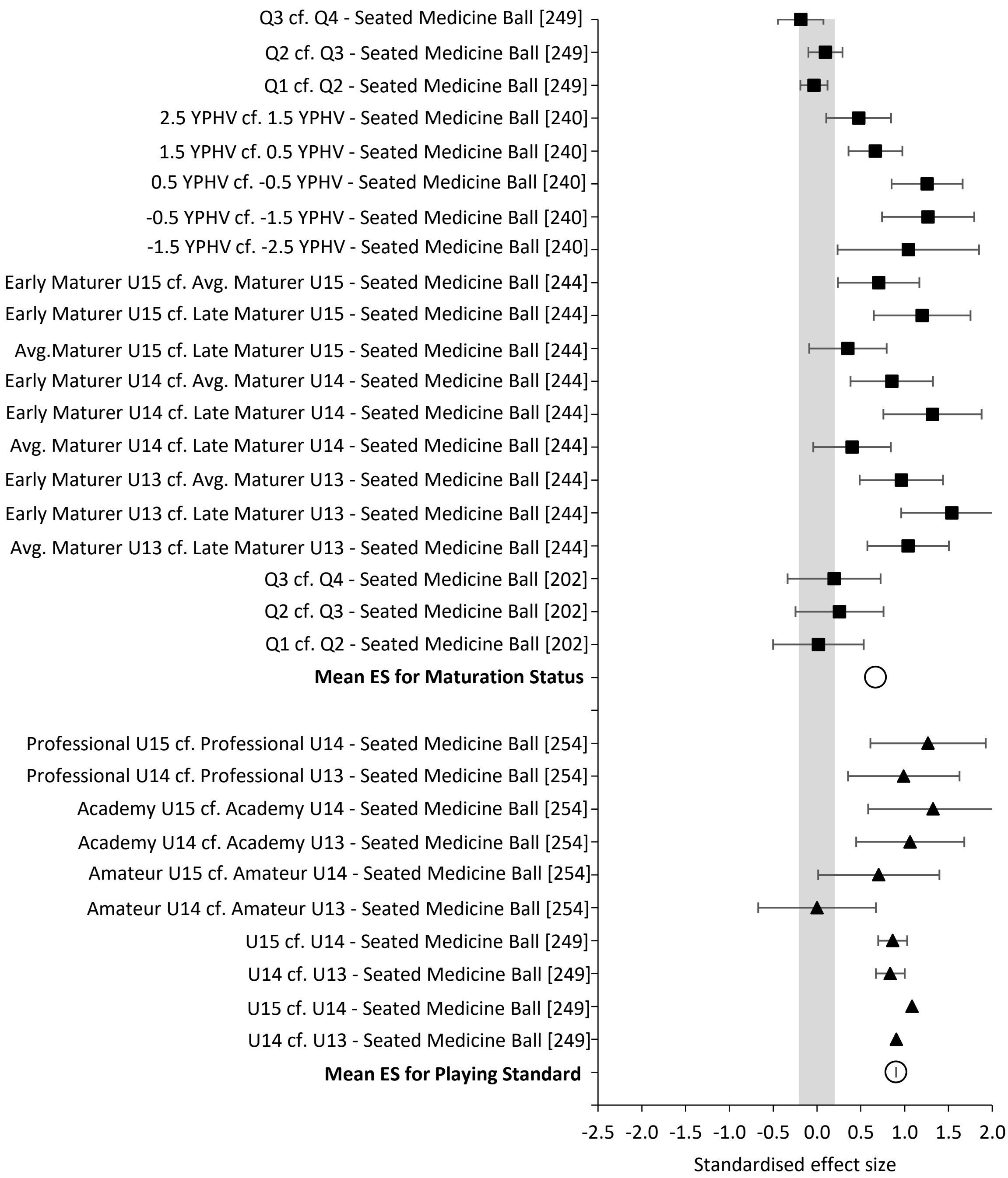


Figure 5. Standardised differences (±90% CI) in seated medicine ball throw with respect to maturation status (squares) and playing age (triangles). Q = quartile. YPHV = years at peak height velocity. Open circles represent the mean effect size.

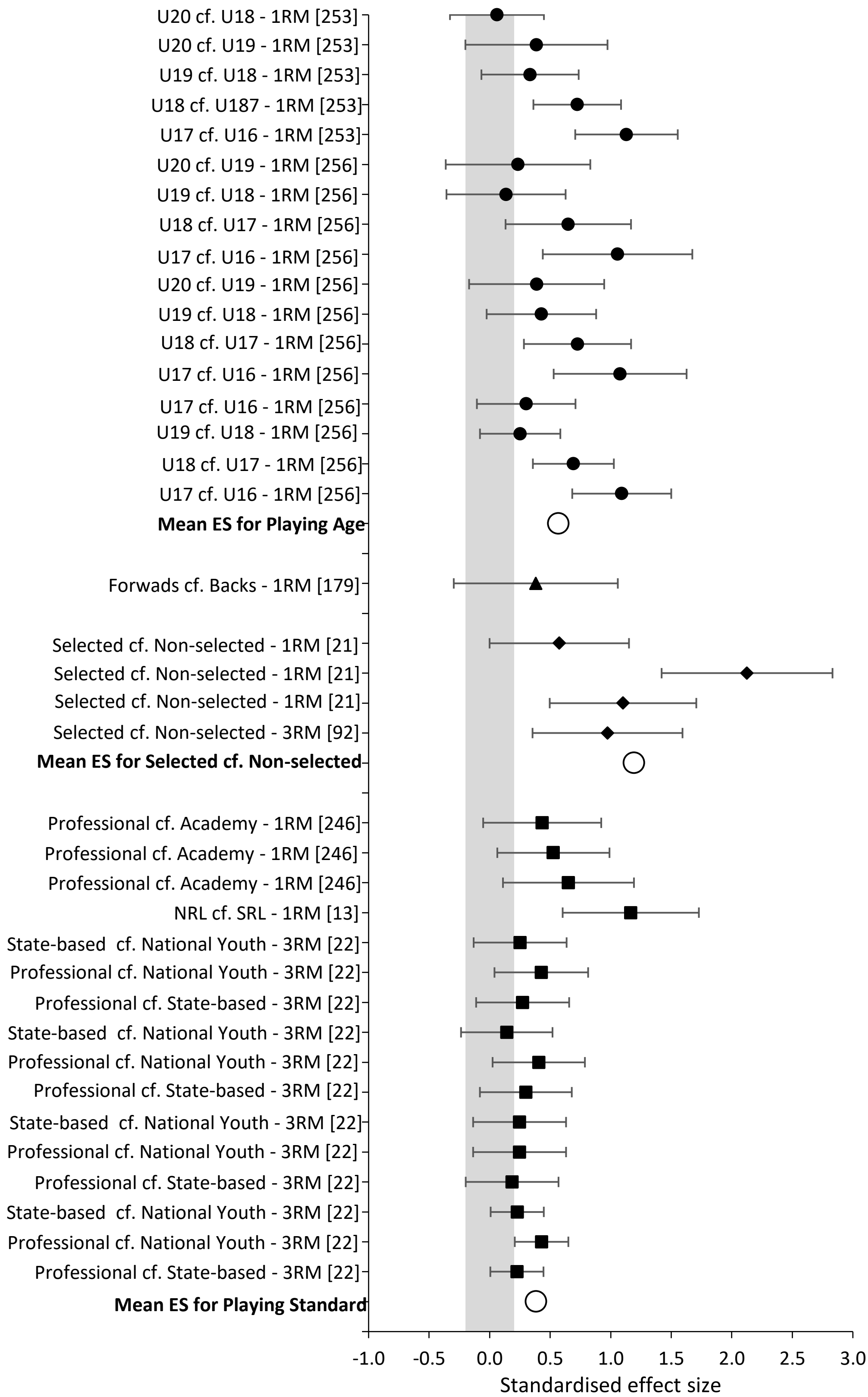


Figure 6. Standardised differences (±90% CI) in lower-body strength between playing ages (circles), positions (triangles), selected/non-selected (diamonds) and playing standards (squares) for measures of lower-body strength. RM = repetition maximum. NRL = national rugby league. SRL = state rugby league. Open circles represent the mean effect size.

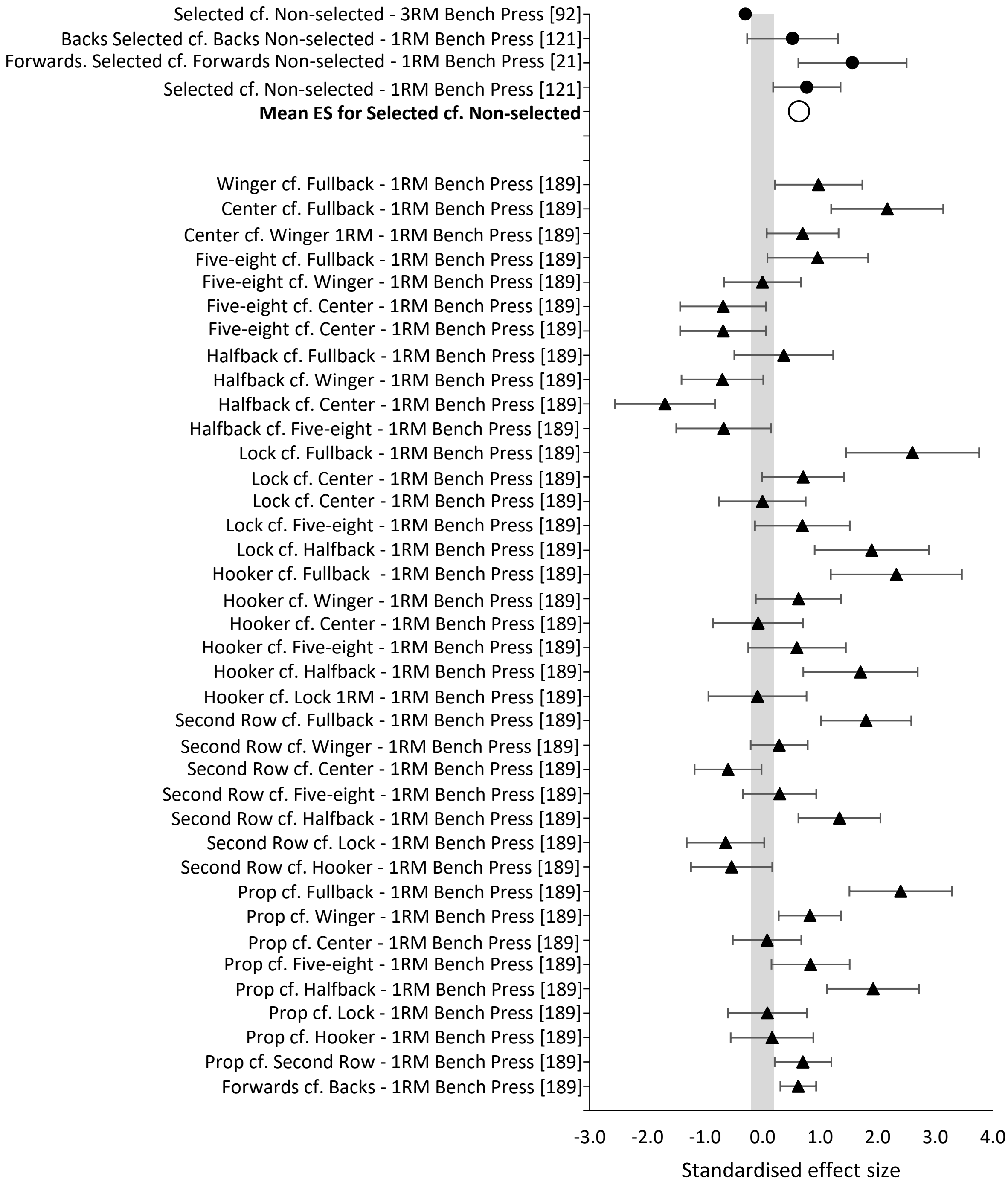


Figure 7. Standardised differences (±90% CI) between selected/non-selected players (circles) and playing positions (triangles) for measures of upper-body strength. RM = repetition maximum. Open circle represents the mean effect size.

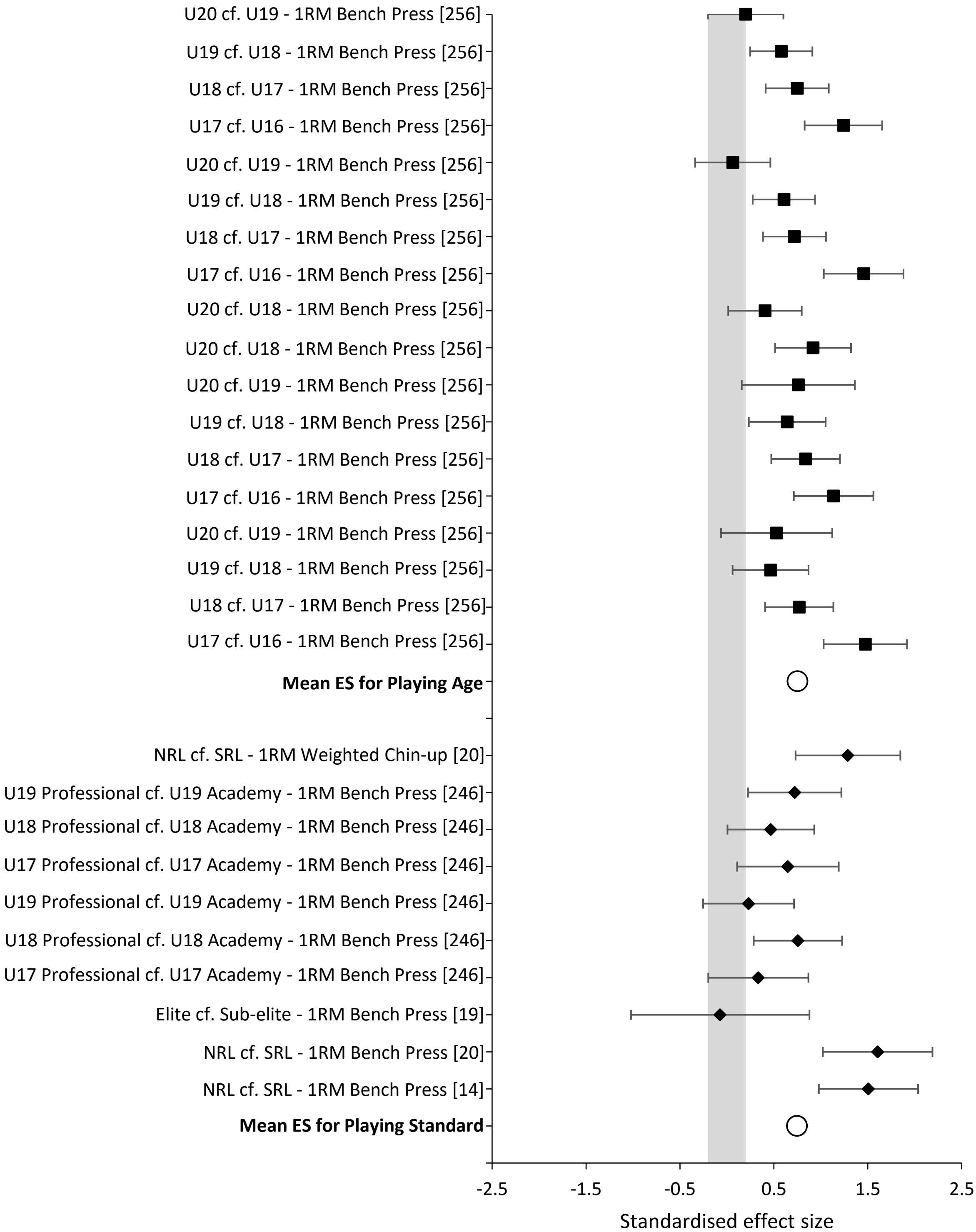


Figure 8. Standardised differences (±90% CI) in playing ages (squares) and playing standards (diamonds) for upper-body strength measures. RM = repetition maximum. NRL = national rugby league. SR = state rugby league. Open circle represents the mean effect size.

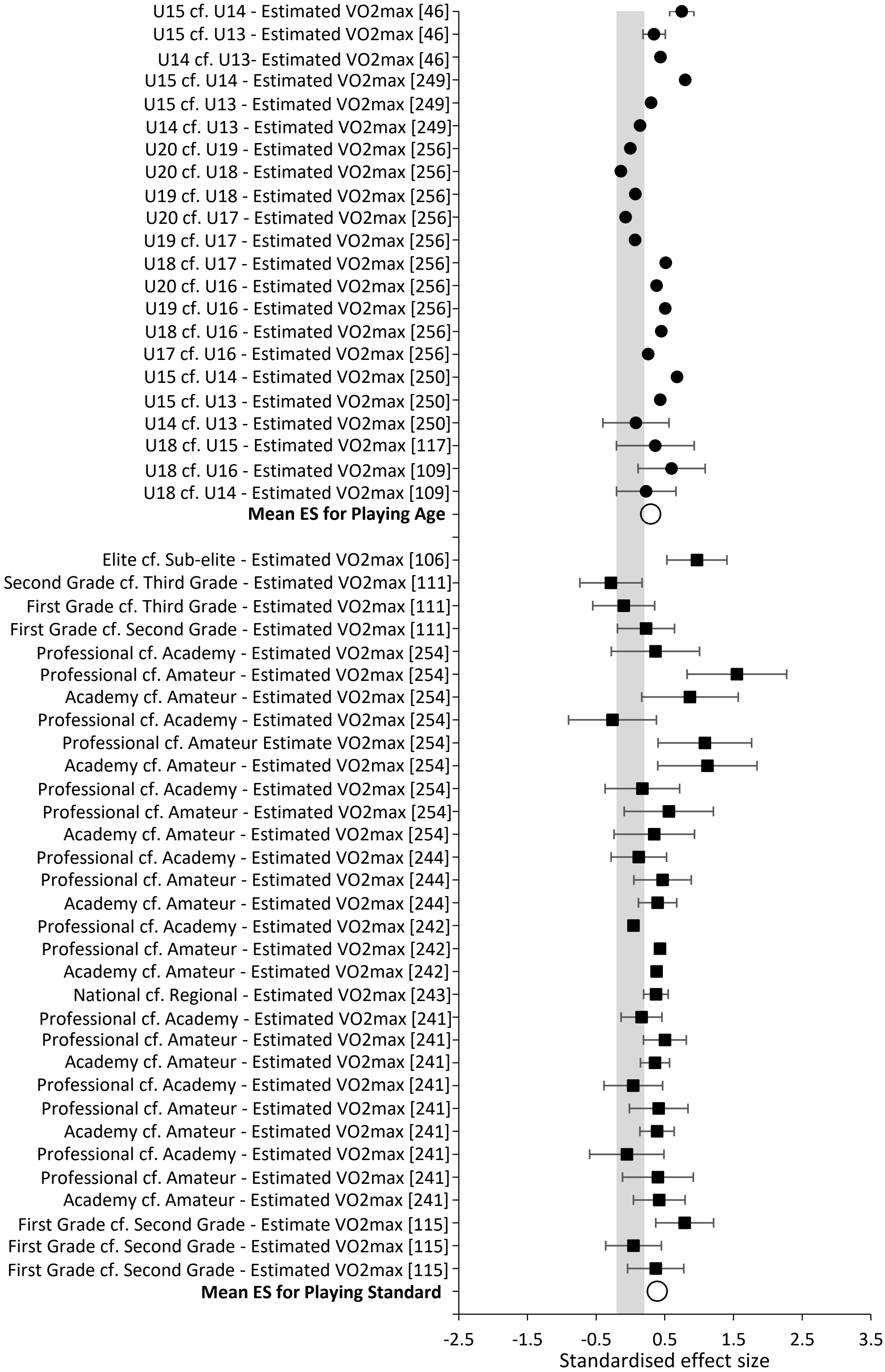


Figure 9. Standardised differences (±90% CI) between playing ages (circles) and performance standards (squares) for estimated VO_{2max}. Open circle represents the mean effect size.

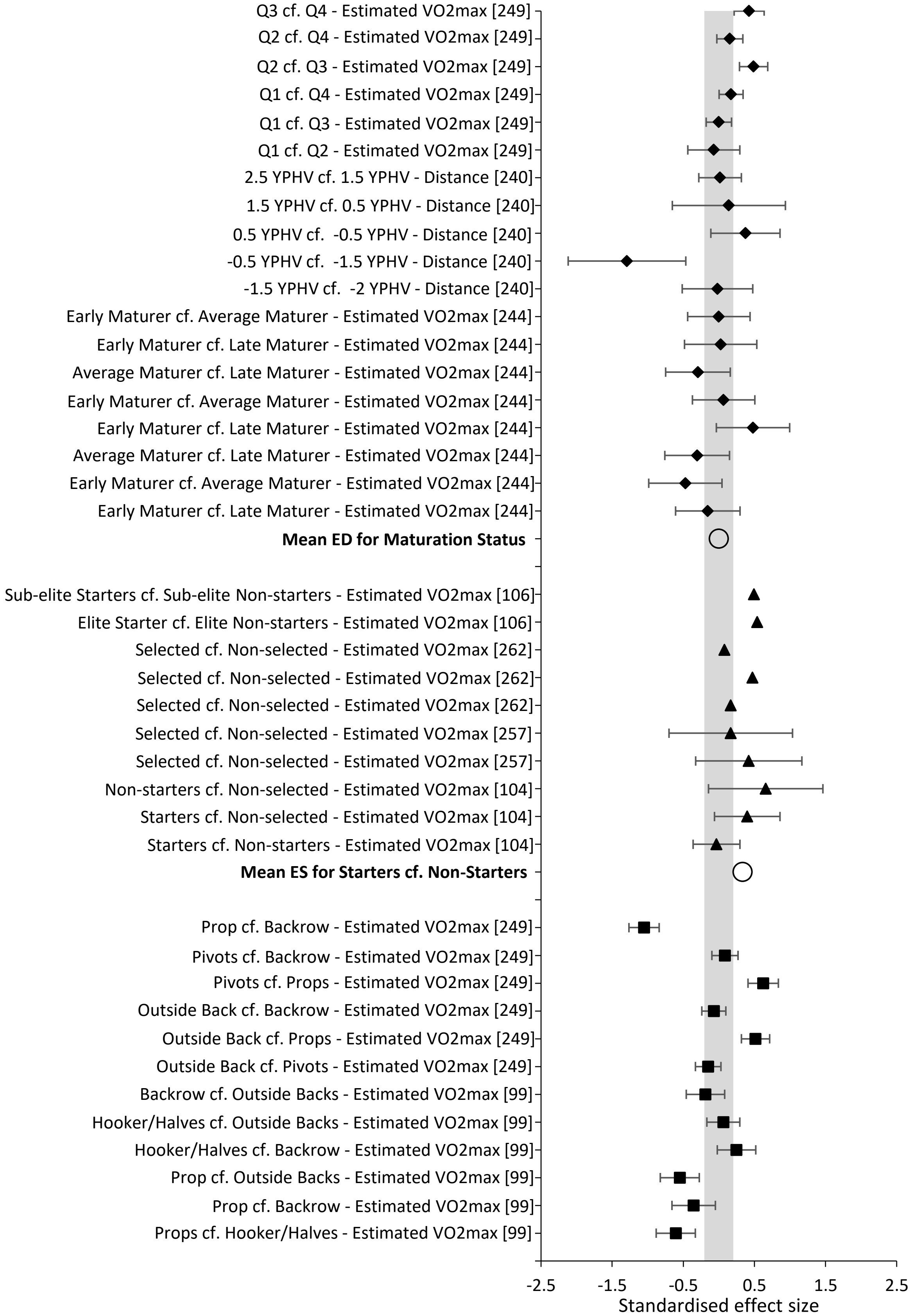


Figure 10. Standardised differences (±90% CI) between maturation status (diamonds), selected/non-selected (triangle) and playing positions (squares) for estimated VO_{2max}. YPHV = years at peak height velocity. Q = quartile. Open circles represent the mean effect size.

Appendix 9.

Linear mixed model output

Effect of fixed factors on body mass (90%CI).

Body mass (model 1)	**Coefficient**	**90% CI**	**df**	***t*-value**	**η^2**
Intercept (kg)	80.19	76.37, 84.02	229	34.621	
End of Preseason	1.12	0.56, 1.69	190	3.312	0.23
Mid-Season	1.24	0.84, 1.64	265	5.103	0.30
End Preseason	0.50	0.15, 0.84	240	2.379	0.15
Hooker	-3.42	-8.05, 1.21	215	-1.219	-0.08
Centre	4.03	0.06, 7.99	234	1.677	0.11
Second Row	7.34	3.17, 11.51	215	2.906	0.19
Prop	10.35	6.52, 14.18	229	4.465	0.28
Loose Forward	3.84	-0.27, 7.95	217	1.543	0.10
Scrum Half	-7.35	-13.3, -1.42	218	-2.050	-0.14
Second Year	3.73	1.49, 5.97	264	2.745	0.17
Third Year	3.48	1.36, 5.59	291	2.710	0.16
Countermovement Jump (cm)	-0.07	-0.13, -0.02	502	-2.308	-0.10
Change of Direction (s)	0.46	0.19, 0.73	451	2.805	0.13
Medicine Ball Throw (m)	0.83	0.48, 1.17	468	3.979	0.18
Prone Yo-Yo IR1 (m)	-0.00	-0.00, -0.00	531	-2.760	-0.12

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Effect of fixed factors on 8-site skinfold thickness (90%CI).

∑Skinfolds	**Coefficient**	**90% CI**	**df**	***t*-value**	**η^2**
Intercept (mm)	93.76	79.73, 107.7	79	11.124	
End of Preseason	-4.97	-8.11, -1.82	65	-2.630	-0.31
Mid-Season	-11.92	-14.47, -9.36	68	-7.791	-0.68
End Preseason	-9.57	-12.20, -6.95	65	-6.080	-0.60
Halfback	10.07	-8.22, 28.36	73	0.917	0.11
Prop	7.51	9.21, 24.23	87	0.747	0.08
Loose Forward	25.53	7.98, 43.06	77	2.422	0.26
Scrum Half	20.87	2.40, 39.33	75	1.882	0.21
Body mass (kg)	1.75	1.39, 2.09	196	8.309	0.51

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Effect of fixed factors on change of direction time (90%CI).

Change of Direction	**Coefficient**	**90% CI**	**df**	***t*-value**	η^2
Intercept (s)	20.20	19.99, 20.42	274	15.591	
End of Preseason	-0.39	-0.47, -0.29	284	-7.065	-0.39
Mid-Season	-0.17	-0.27, 0.08	327	-3.064	-0.17
End Preseason	-0.26	-0.35, -0.18	338	-5.120	-0.27
Winger	-0.50	-0.76, -0.24	215	-3.226	-0.21
Loose Forward	-0.17	-0.42, 0.07	223	-1.190	-0.08
Body Mass (kg)	0.01	0.00, 0.08	295	3.635	0.21
20 m Sprint Time (s)	1.97	1.47, 2.48	768	6.470	0.23
Countermovement Jump (cm)	-0.02	-0.02, -0.01	500	-3.734	-0.16
Prone Yo-Yo IR1 (m)	-0.00	-0.00, -0.00	597	-3.644	-0.15

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Effect of fixed factors on 20 m sprint time (90%CI).

20 m Sprint Time	**Coefficient**	**90% CI**	**df**	***t*-value**	η^2
Intercept (s)	3.06	3.04, 3.08	362	238.870	
End of Preseason	0.03	0.02, 0.04	458	3.821	0.18
Mid-Season	0.03	0.02, 0.04	481	3.921	0.18
End Preseason	0.03	0.02, 0.05	447	4.968	0.23
Hooker	0.03	0.01, 0.05	230	2.073	0.14
Halfback	0.03	0.01, 0.085	224	2.365	0.16
Second Row	0.02	-0.00, 0.04	225	1.287	0.09
Prop	0.03	0.01, 0.05	227	2.852	0.19
Winger	0.02	-0.00, 0.04	225	1.450	0.10
Loose Forward	0.02	-0.00,0.04	230	1.483	0.10
Scrum Half	0.03	0.00, 0.06	234	1.840	0.12
Stand-off	0.03	0.00, 0.06	237	1.787	0.12
Top	-0.02	-0.03, -0.01	219	-3.334	-0.22
Middle	0.03	0.01, 0.04	205	2.885	0.20
Body Mass (kg)	0.00	-0.00, 0.00	246	1.223	0.08
10 m Sprint Time (s)	1.01	0.97, 1.06	624	39.766	0.85
Countermovement Jump (cm)	-0.003	-0.00, -0.00	398	-6.55	-0.31
Change of Direction (s)	0.03	0.02, 0.03	663	7.570	0.28

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Effect of fixed factors on 10 m sprint time (90%CI).

10 m Sprint Time	**Coefficient**	**90% CI**	**df**	***t*-value**	η^2
Intercept (s)	1.84	1.81, 1.86	47	161.933	
End of Preseason	-0.02	-0.03, -0.01	335	-3.704	-0.20
Mid-Season	-0.03	-0.04, -0.02	439	-6.277	-0.29
End Preseason	-0.02	-0.03, -0.02	427	-5.256	-0.25
Hooker	-0.02	-0.04, 0.00	38	-1.667	-0.26
Prop	-0.02	-0.03, 0.01	40	-1.529	-0.23
Scrum Half	-0.03	-0.04, 0.02	41	-1.601	-0.24
Third Year	0.01	-0.00, 0.02	38	1.380	0.22
20 m Sprint Time (s)	0.61	0.58, 0.64	179	41.468	0.95
Prone Yo-Yo IR1 (m)	0.02	0.00, 0.04	112	2.193	0.20

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Effect of fixed factors on medicine ball throw distance (90%CI).

Medicine Ball Throw	**Coefficient**	**90% CI**	**df**	***t*-value**	η^2
Intercept (m)	7.04	6.80, 7.28	247	48.671	
End of Preseason	0.41	0.33, 0.49	214	8.847	0.52
Mid-Season	0.20	0.14, 0.27	232	5.063	0.31
Halfback	0.20	-0.09, 0.49	228	1.160	0.08
Centre	0.19	-0.08, 0.48	234	1.181	0.08
Second Row	0.33	0.04, 0.62	230	1.899	0.12
Winger	0.42	0.13, 0.73	226	2.325	0.15
Loose Forward	0.43	0.14, 0.71	233	2.489	0.16
Scrum Half	-0.32	-0.73, 0.09	240	-1.301	-0.08
Stand-off	0.36	-0.05, 0.77	232	1.458	0.10
Body Mass (kg)	0.04	0.03, 0.04	373	10.431	0.48
20 m Sprint Time (s)	-0.31	-0.73, 0.10	455	-1.236	-0.06
Countermovement Jump (cm)	0.04	0.03, 0.04	626	7.054	0.27

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Effect of fixed factors on countermovement jump height (90%CI).

Countermovement Jump	**Coefficient**	**90% CI**	**df**	***t*-value**	η^2
Intercept (cm)	40.95	39.29, 42.42	233	40.691	
End of Preseason	1.68	1.10, 2.26	270	4.792	0.28
Mid-Season	1.36	0.88, 1.83	233	4.748	0.30
End Preseason	0.89	0.43, 1.37	232	3.152	0.20
Hooker	-4.97	-7.15, -2.79	218	-3.776	-0.25
Halfback	-1.95	-3.93, 0.03	213	-1.625	-0.11
Centre	-4.58	-6.49, -2.68	217	-3.986	-0.26
Second Row	-2.90	-4.88, -0.92	215	-2.425	-0.16
Prop	-4.04	-5.92, -2.16	227	-3.554	-0.23
Loose Forward	-3.73	-5.68, -1.78	219	-3.166	-0.21
Scrum Half	-8.41	-11.21, -5.61	219	-4.959	-0.32
Stand-off	-5.25	-8.03, -2.47	216	-3.116	-0.21
Middle	3.48	2.02, 4.93	213	3.951	0.26
Body Mass (kg)	-0.15	-0.19, -0.11	457	-5.851	-0.26
10 m Sprint Time (s)	2.40	-1.07, 5.88	541	1.140	0.05
20 m Sprint Time (s)	-8.30	-11.08, -5.51	548	-4.904	-0.20
Change of Direction (s)	-0.69	-1.01, -0.36	613	-3.496	-0.14
Medicine Ball Throw (m)	1.25	0.90, 1.59	559	5.994	0.25

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Effect of fixed factors on prone Yo-Yo IR1 (90%CI).

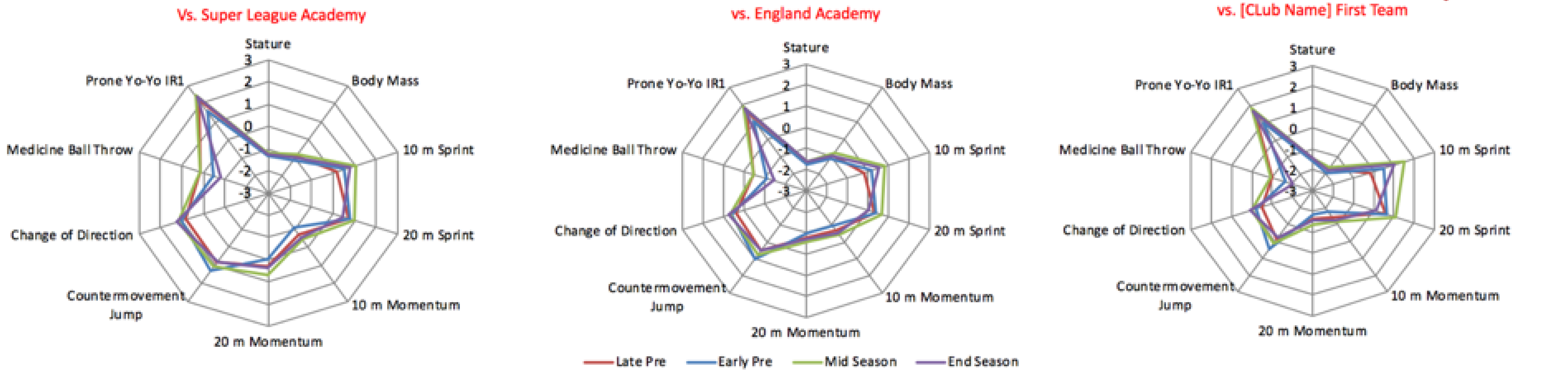
Prone Yo-Yo IR1	**Coefficient**	**90% CI**	**df**	***t*-value**	η^2
Intercept (m)	909.3	829.5, 989.1	248	18.805	
End of Preseason	50.9	24.90, 76.9	215	3.234	0.22
Mid-Season	136.4	113.7, 159.0	239	9.932	0.54
End Preseason	97.6	76.5, 118.7	230	7.645	0.45
Hooker	109.0	3.3, 214.7	241	1.703	0.11
Centre	-126.3	-218.7, -34.0	242	-2.258	-0.14
Second Row	-115.0	-210.8, -19.3	256	-1.985	-0.13
Prop	-246.0	-337.0, -155.0	247	-4.463	-0.27
Winger	-178.7	-279.2, 78.2	236	-2.936	-0.19
Loose Forward	-142.6	-236.6, -48.5	238	-2.503	-0.16
Stand-off	-119.1	-253.6, 15.4	234	-1.463	-0.10
Top	98.4	58.3, 138.6	230	4.052	0.26
Middle	131.6	61.9, 201.3	228	3.117	0.20
Body Mass (kg)	-3.956	-5.9, -1.9	390	-3.244	-0.16
Countermovement Jump (cm)	2.22	-0.50, 4.94	665	1.346	0.05
Change of Direction (s)	-40.8	-65.1, -25.5	599	-4.395	-0.18

CI: confidence interval; df: degrees of freedom; η^2: effect size correlation.

Appendix 10. Example of player feedback

Rugby League Athlete Profiling

Name: **Position** **Hooker** **Age** **18**



Where you comapre to England Academy

	Graph Number	Stature	Body mass	10 m	20 m	10 Momentum	20 Momentum	CMJ	Agility	Med ball	Prone Yo-Yo
V. Good	3			1.61	2.61	560.50	593.00	45.30	18.18	9.60	1200.00
Good	2			1.68	2.76	526.50	574.00	42.40	18.68	8.90	1080.00
Above Avg.	1	188.10	93.10	1.70	2.91	492.50	555.00	39.50	19.18	8.20	960.00
Average	0	180.50	81.80	1.79	3.06	458.50	536.00	36.60	19.68	7.50	840.00
Below Avg.	-1	172.90	70.50	1.86	3.21	424.50	517.00	33.70	20.18	6.80	720.00
Poor	-2			1.99	3.36	390.50	498.00	30.80	20.68	6.10	600.00
V. Poor	-3			2.12	3.51	356.50	479.00	27.90	21.18	5.40	480.00
YOU		**173.00**	**77.10**	**1.75**	**3.07**	**456.21**	**519.19**	**43.83**	**19.17**	**6.51**	**1560.00**

Report produced by Nick Dobbin @ Department of Sport and Exercise Sciences, University of Chester and The Rugby Football League

Appendix 11. Validity of a jump mat for assessing countermovement jump performance in elite rugby players.

Introduction

Rugby league is a multiple sprint collision sport that requires highly developed physical qualities.[5,15,23,33] Of these, lower-body power has been identified as an essential quality for rugby league players[5,10,14] showing strong associations with successful skill execution (i.e. tackling proficiency)[12,33,38] and reducing post-match fatigue.[20,21] Countermovement jump (CMJ) performance differentiates between starters and non-starters,12 playing standard (club cf. international)[35] and playing position.[22] Therefore, CMJ is regularly employed by practitioners to assess the effectiveness of a conditioning programme,[26,29,34,39] to profile players and identify talent[35] and to monitor recovery status.[21,27,36,37]

Whereas video analysis and force platforms are recognised as criterion methods for measuring jump height, flight time and muscle power, these are expensive and not easily accessible for most rugby league clubs.[18,25,31] Flight time and jump height during the CMJ are routinely measured by rugby league practitioners using commercially available equipment such as the Just Jump System® (JJS), to provide estimates of jump performance.[28,30,39] However, the ability of the JJS to accurately measure flight time and jump height has recently been questioned.[28,29] The authors reported that flight time and jump height measured on the JJS and force platform are highly related, but that flight time is on average 105 ms longer on the JJS resulting in an overestimation of jump height.[28,39] Whilst both studies provided a correction equation for the measurement of jump height, neither provided a correction equation for the measurement of flight time, which has been reported to be a more reliable determinant of jump performance.[6] Also, the equations provided were not cross-validated using a sub-sample and therefore their agreement with the criterion method is unknown. Although the authors[28,29] reported a strong correlation between methods, the random error associated with these measurements was not assessed and therefore the application of these corrected equations in the applied environment also remains unknown.

As jump mats are unable to measure muscle power, several prediction equations have been developed that allow practitioners to calculate muscle power using jump height and body mass.[4,7,16,32] Whilst some prediction equations demonstrate no systematic difference to power recorded on a force platform,[16] the accuracy of the equation is highly dependent upon the population it is derived from.[25] For example, the use of previously established prediction equations[16,32] for estimating muscle power in specifically trained team sport athletes are known to underestimate true PPO by 3.3 - 19.4%.[8,18]

In professional rugby league, where the accurate assessment of CMJ performance using a jump mat seems important, recently developed prediction equations[28,39] are not suitable given that they were developed using non-elite populations. Moreover, where the assessment of muscle power is of interest[38] the application of established prediction equations might result in an underestimation of the player's actual PPO. Therefore, the aims of this study were to: a) quantify the difference in jump height and flight time between the JJS and force platform and, if required, develop and cross-validate a correction equation for elite rugby league players; and b) develop and cross-validate a prediction equation for PPO in elite rugby league players.

Material & Methods

Participants and design

With institutional ethics approval and informed consent, 37 elite senior rugby league players from two professional Super League teams (age = 23.3 ± 4.0 y, stature = 182.0 ± 5.5 cm, body mass = 96.8 ± 9.0 kg) participated in this study. A sub-sample of 28 elite senior players from one professional Super League club (age = 23.4 ± 4.3 y, stature = 181.9 ± 5.5 cm, body mass = 96.1 ± 9.0 kg) was later recruited to cross-validate the equations for jump height, flight time and power output. All testing procedures were conducted in accordance with the ethical standards of the International Journal of Sports Medicine.[17]

In one visit, participants completed one practice jump followed by six CMJs; three using their arms (*with* arms; n = 111) and three with their hands on their hips (*without* arms; n = 108), interspersed by 60 s recovery between jumps. All participants were familiar with the procedures as this was part of their weekly monitoring processes. To cross-validate the data, the sub-sample of participants attended a second session five days after the first at a similar time of day (± 2 hours) and completed two CMJs, one *with* (n = 28) and one *without* arms (n = 28), interspersed by 60 s recovery.

Procedures

For the CMJ, participants maintained a stance with feet positioned shoulder width apart before flexing their knees in a rapid downward motion and extending into the jump. To standardise the jumps participants had to have been judged to reach approximately 90° knee flexion[37] and keep their legs straight throughout the jump (i.e. not lifting knees or bringing their heels towards their buttocks). Those jumps (n = 3 *without* arms) that did not meet these criteria were excluded from the analysis. Each jump was performed on a timing mat (Just Jump System, Probotics, Huntsville, Alabama, USA) that was positioned on top of a 600 X 600 mm uni-axial calibrated force platform (HUR Labs, FP4, Tampere, Finland) sampling at 1200 Hz. The jump mat was positioned on the force platform before calibration and allowed both apparatus to record measurements simultaneously.[25] Both flight time and jump height derived from the JJS and force platform were displayed on a hand held computer and on custom software (HUR Labs Force Platform Software Suite), with jump height calculated using the following equation:[24]

$$\text{Jump height} = (\text{flight time}^2 \times g)\ 8^{-1}$$

In this equation, g denotes the acceleration of gravity (9.81 $m \times s^{-2}$). For the JJS, flight time was measured as the time the participant was in the air and was detected by the micro switches embedded within the mat sampling at 100 Hz.[39] For the force platform, flight time was also determined as the time the participant was in the air with < 5 N being used to detect take-off and > 50 N for landing. To ascertain PPO the force platform used the following in-built equations:

Force = average force at point of take-off and landing

Momentum = (momentum + average force) x (1 / 1200)

Impulse = (momentum x impulse / weight x 1) x (1 / 1200)

PPO = (force x impulse / mass)

The within-session coefficient of variation for flight time during the first session was 4.8% and 5.0% for *with* and *without* arms, respectively.

Statistical Analyses

Data were initially checked for normality via the Kolmogorov-Smirnov statistic before using Pearson product-moment correlation (*r*-value) to check for heteroscedastic errors. Data that demonstrated heteroscadascity was log-transformed to reduce the error.[2] Paired sample *t*-tests were used to calculate differences (biases) between means of measurement methods. In order to make comparisons, the coefficient of variation (CV: *SD*/Mean x 100) was also used to assess validity and was quantified in accordance with previous research.[2] Linear and multiple regression analysis was used to determine a correction equation for flight time and jump height and to develop a new prediction equation for PPO. Collinearity was assessed before the multiple regression and indicated that there was a high collinearity between jump height and flight time (*with* $r = 0.992$; *without* $r = 0.996$), hence jump height was excluded. Weak collinearity (*with* $r = -0.366$; *without* $r = -0.292$) existed between flight time and body mass, with both variables contributing significantly to predictive model. Data are reported as mean and standard deviation(s) throughout and analysed using SPSS for Windows (Version 22.0, 2013).

Results

There was a positive relationship between CMJ flight time derived from the JJS and force platform *with* ($r = 0.969$, $P < 0.001$) and *without* ($r = 0.986$, $P < 0.001$) arms, which resulted in adjusted coefficient of determinations (R^2) of 0.938 and 0.972, respectively (Figure 1). A positive relationship was also present between jump height derived from the JJS and force platform *with* (r = 0.972, P < 0.001) and *without* arms (r = 0.994, P < 0.001), resulting in adjusted R^2 values of 0.945 and 0.988, respectively. Despite the strong relationship between methods, ratio LoA indicated that there was a systematic (P < 0.05) overestimation of flight time and jump height, *with* and *without* arms using the JJS compared to the force platform (Table 1). Given the near perfect R^2 between the two systems, linear regression analysis was used to establish four correction equations, allowing practitioners within the field of rugby league to accurately measure jump height and/or flight time *with* and *without* arms from the JJS (Figure 1).

Table 1. Validity of Just Jump® against force platform to measure jump height and flight time.

	Just Jump®	Force platform	Ratio 95% LoA	CV%	Adjusted R^2
Jump height (cm)					
With arms	53.69 ± 6.14*	40.28 ± 5.10	1.34 x/÷ 1.06	18.68	0.938
Without arms	48.62 ± 5.51*	35.81 ± 4.72	1.15 x/÷ 1.03	19.48	0.972
Flight time (s)					
With arms	0.66 ± 0.04*	0.57 ± 0.04	1.36 x/÷ 1.05	9.15	0.945
Without arms	0.62 ± 0.03*	0.54 ± 0.03	1.16 x/÷ 1.03	9.40	0.988

Note: LoA = limits of agreement. CV% = coefficient of variation. *Significantly higher than criterion (P<0.05).

Table 2. Validity of correction equations against measured jump height and flight time using cross-validation sample.

	Corrected	Force platform	95% Ratio LoA	CV%	Adjusted R^2
Jump height (cm)					
With arms	45.99 ± 5.69	46.36 ± 6.06	1.01 x/÷ 1.17	14.35	0.924
Without arms	41.00 ± 4.87	41.36 ± 5.70	1.01 x/÷ 1.19	14.43	0.966
Flight time (s)					
With Arms	0.61 ± 0.04	0.62 ± 0.05	1.00 x/÷1.13	7.34	0.914
Without arms	0.58 ± 0.03	0.58 ± 0.41	1.00 x/÷ 1.11	7.20	0.937

Note: LoA = limits of agreement. CV% = coefficient of variation. *Significantly higher than criterion (P<0.05). Shrinkage = 2.22% and 2.23% for jump height and 2.56 and 3.60 for flight time *with* and *without* arms, respectively.

The adjusted R^2 between criterion and corrected flight time and jump height *with* and *without* arms were strong (Figure 1) and demonstrated a reduced systematic bias ($P > 0.05$) compared to the uncorrected scores (Table 2). Cross-validation analyses for flight time and jump height revealed an adjusted R^2 (flight time: *with* 0.924; *without* 0.966; jump height: *with* 0.914; *without* 0.937) that represented a shrinkage of 2.22%, 2.23%, 2.56% and 3.60%, respectively.

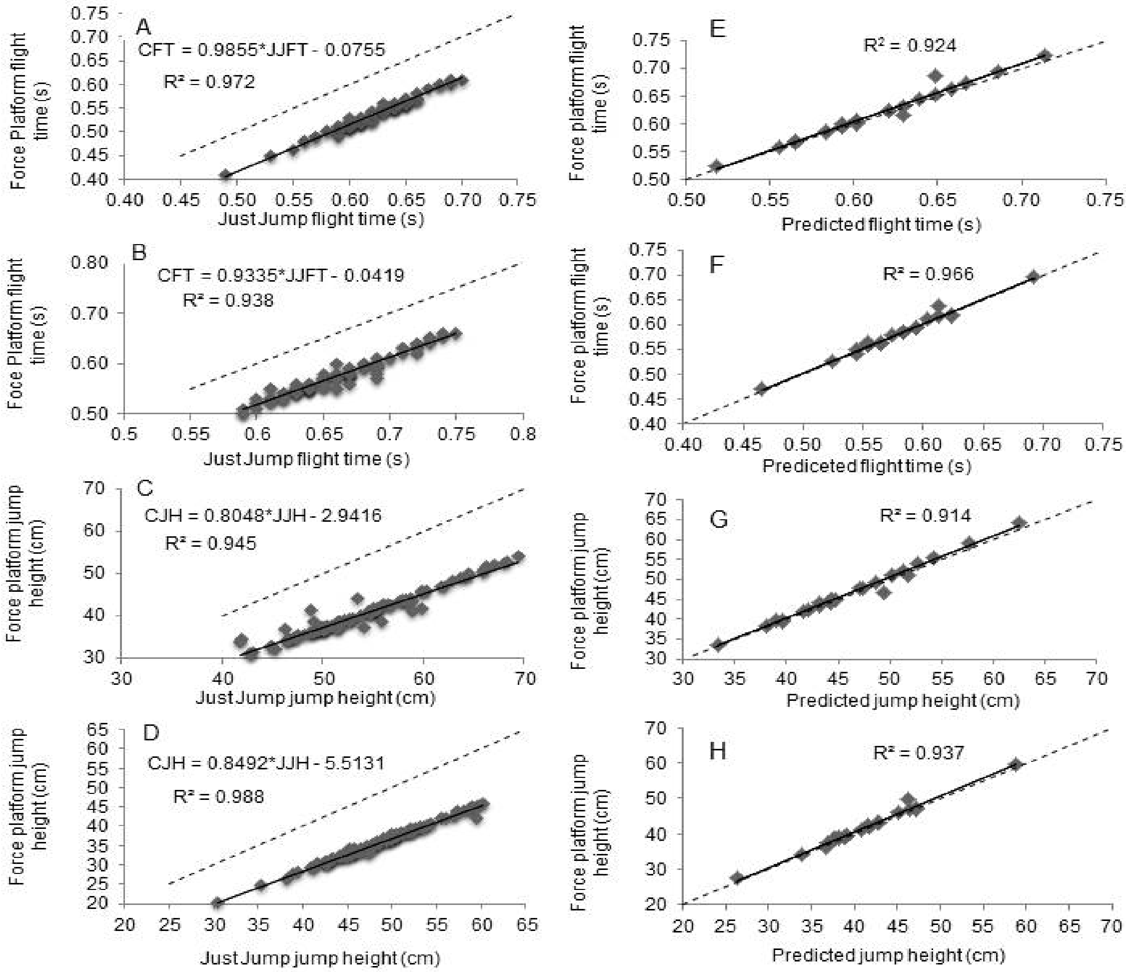


Figure 1. Relationship between JJS and force platform for flight time *with* (A; n = 111) and *without* (B; n = 108) arms and jump height *with* (C; n = 111) and *without* (D; n = 108) arms and the relationship between the correction equation and force platform for flight time *with* (E; n = 28) and *without* (F; n = 28) arms and jump height *with* (G; n = 28) and *without* (H; n = 28) arms. R^2 = adjusted coefficient of determination. CFT = criterion flight time, JJFT = Just Jump flight time, CJH = criterion jump height and JJH = Just Jump height). The dashed line represents the line of identity (force platform = Just Jump System).

Stepwise regression analysis was used to predict PPO (W) from flight time (s) and body mass (kg). The two predictor variables accounted for a significant proportion of variability in PPO, *with* (adjusted $R^2 = 0.642$, $F = 96.52$, $P < 0.001$) and *without* arms (adjusted $R^2 = 0.691$, $F = 111.34$, $P < 0.001$). However, the regression model for PPO *with* (PP_{est} = 12413.90 x (flight time) + 58.77 x (body mass) – 7383.05) and *without* arms (PP_{est} = 8167.97 x (flight time) + 49.13 x (body mass) – 4390.76) showed a large degree of random error (Table 3). Cross-validation analysis revealed an adjusted R^2 (*with* 0.613*; without* 0.654) that represented shrinkage of 4.52% and 5.36% relative to the cross-validation model (*with* 64.2%; *without* 69.1%).

Table 3. Validity of prediction equations for peak power

	Peak power output (W)	SEE	Ratio 95% LoA	CV%	Adjusted R^2
Measured					
With arms	5846.9 ± 651.6	-	-		-
Without arms	5048.2 ± 589.0	-	-		-
Predicted					
With arms	5930.0 ± 603.2	410.6	1.02 x/÷ 1.17	10.69	0.613
Without arms	5060.4 ± 479.0	310.0	1.01 x/÷ 1.15	10.91	0.654
Harman et al. (1991)					
Without arms	4205.6 ± 417.3*	-	1.20 x/÷ 1.16	14.55	0.77
Sayers et al. (1999)					
Without arms	4837.7 ± 458.3*	-	1.04 x/÷ 1.16	11.18	0.78

Note: SEE = standard error of estimate. LoA = limits of agreement. CV% = coefficient of variation. *Significantly difference to actual peak power (P<0.05). Shrinkage = 4.52% and 5.36% for *with* and *without* arms, respectively.

Discussion

The primary aim of this study was to establish the criterion validity of the JJS against a force platform for measuring flight time and jump height during a CMJ in elite rugby league players. In accordance with previous studies,[28,39] we report a systematic overestimation of flight time and jump height derived from the JJS. On average, flight time was 85 ms longer using the JJS compared to the force platform, which resulted in an overestimated jump height of ~13 cm. The ratio LoA indicated that for a player with a flight time of 0.50 s using the force platform, they could, in the worst case scenario, achieve a value between 0.56 and 0.59 s *with* and 0.56 and 0.60 s *without* arms when using the JJS. Furthermore, the ratio LoA for jump height indicated that a player who jumped 30 cm using the force platform, could jump between 37.9 and 42.6 cm and 38.9 and 42.8 cm *with* and *without* arms, respectively, when measured using the JJS. Our findings reaffirm previous work[28,39] that the JJS does not provide a valid measure of flight time or jump height during a CMJ.

Several reasons might explain the observed differences between measurement systems. McMahon et al.[28] suggested that jump height might have been overestimated due to the JJS requiring a large minimal force for the microswitches within the mat to detect the take-off and landing during the CMJ. Whilst this might explain some of the difference, it is important to note that the JJS does not directly measure jump height but calculates this from fight time. Therefore, any delay in the microswitches to detect the landing is likely to results in a large overestimation in flight time. Whitmere et al.[39] proposed that due to the consistent differences between methods, approximately 100 ms have been added to the algorithm used to calculate flight time. However, as the algorithms used are unknown, it is difficult to conclude that this is the case, despite our results showing a similar trend. The observed difference might also be explained by the higher sampling frequency of the force platform (1200 Hz) compared to the JJS (100 Hz). Such large differences are likely to result in different detection rates during the take-off and landing, influencing the accuracy of flight time and subsequently jump height.

Using the correction equations, results revealed that the accuracy of flight time and jump height were improved (Table 2) and could, therefore, be used by practitioners to accurately measure jump performance. The results indicate that the correction equations removed the over-estimation created by the JJS and reduced the mean bias. As a result, the potential range of scores achieved now encompasses the measured score and therefore, one can be 95% confident that the same participant who scored 30 cm on their first trial (*with arms*), could score between 25.8 and 35.4 cm during their second trial. Based on these calculations, it appears that the JJS and the correction equation are, in some cases, not sensitive enough to detect small, but potentially meaningful changes in jump performance. For example, Gabbett[14] reported a 4.2 cm increase in CMJ performance in junior rugby league players after a 14-week training intervention. Based on our analysis, it is possible, in some cases, this improvement would not be detected using the JJS or the correction equation due to the large random error associated with this method.

The second aim of this study was to develop an equation for predicting PPO in elite rugby league players. Whereas previous work has used jump height,[28,39] our analysis indicated that flight time was a better predictor of PPO. The use of flight time is somewhat understandable since it is measured directly by the JJS and is a more reliable performance indicator of jump performance.[6] The results support previous observations[8,18] that PPO estimated using equations derived from non-elite populations underestimates true PPO in well-trained athletes.[16,32] The ratio LoA indicated that there was a systematic under-estimation of PPO when using the Harman et al.[16] and Sayers et al.[32] equations, but not systematically different when using our equations. This finding suggests that when applied to elite rugby league players, these equations are an improvement on those of Harman et al.[16] and Sayers et al.[32] However, the results indicate that a player who achieved a PPO of 5000 W on their first visit (*with arms*), could, in the worst case scenario, score as low as 4359 W or as a high as 5967 W during a second visit. It is likely this degree of random error is too large to detect small but meaningful changes in lower-body power.[1] For example, Speranza et al.[33] reported an improvement in CMJ PPO of ~205 W in senior rugby league players after a 15-week preseason training period. Based on our analysis, it is possible, in some cases, that this improvement in PPO would not be detected using our prediction equation due to the large random error associated with this measure.

Our results support the notion that generalised equations to estimate PPO developed using non-elite populations are unsuitable for elite rugby league players. This might, in part, be explained by the strong emphasis placed on strength and power development in rugby league players[3] that leads to improved neuromuscular characteristics when compared to non-elite populations. Indeed, those athletes requiring highly developed speed, strength and power, have a higher proportion of fast twitch muscle fibres[19] and are capable of producing large ground reaction forces through increased muscle mass, muscle fibre recruitment, co-ordination and firing frequency[9] compared to non-elite populations. These enhanced neuromuscular characteristics mean that elite rugby league players are likely to have an enhanced ability to produce greater force and power during explosive movements such as the CMJ compared to non-elite athletes. This might explain the systematic underestimation of PPO when using equations based on non-elite athletes, suggesting that a more homogenous equation is required. As flight time and body mass only accounted for 64 and 69% of PPO, it is possible that differences in neuromuscular characteristics between players, due different training experiences and genetic differences, could have contributed to the variation in PPO.

Limitations

Whilst our equations for correcting flight time and jump height removed the systematic over-estimation, the large random error associated with these equations could limit their usefulness for detecting small, but potentially meaningful changes in CMJ performance. The PPO prediction equation was an improvement on those previously reported when working with elite rugby league players, but also demonstrated a large random error, which too could limit its application in the applied environment. It is important to note that the correction equations for flight time and jump height, as well as the prediction equation for PPO are specific to the JJS and caution should be taken when applying these equations to other jump mats.

Conclusion

Although attempts have been made to create correction equations for the JJS,[28,39] these authors did not cross-validate their equations or assess the agreement between the equations and force platform. In contrast, the present study established and cross-validated four equations that can be used by applied practitioners to accurately measure jump height and/or flight time when using the JJS. Furthermore, this is the first study to use flight time within the PPO equation. As flight time is measured rather than predicted, this is likely to provide a more accurate and reliable measure of jump performance and therefore should be used for predicting PPO. The results indicate that the prediction equations to estimate PPO of elite rugby league players are an improvement on those reported previously using non-elite participants. However, as the R^2 between the force platform and prediction equations *with* and *without* arms only accounted for 64 and 69% of PPO, it is reasonable to suggest that PPO cannot be estimated accurately using a JJS and that practitioners requiring measures of PPO should use a force platform.

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Appendix 12. Criterion and construct validity of an isometric mid-thigh pull dynamometer for assessing whole-body strength in professional rugby league players.

Introduction

Maximum muscle strength is an important physical quality for rugby league that is related to fundamental performance characteristics (e.g. sprint performance, tackling ability)[1,2,3] and is associated with a lower risk of injury.[4] Maximal strength is also known to differentiate between playing standard,[5-7] meaning it has importance as part of talent identification. Practitioners must therefore be able to accurately assess a rugby league player's whole-body maximal strength.

The assessment of maximal strength using isoinertial measures (e.g. 1RM squat) is traditionally used in rugby league,[1,6,8,9] but can be influenced by individual technique and experience.[10] Isointerial dynamometry is also associated with an increased risk of injury,[11] while testing with large squads can be time consuming. Taken together, the shortcomings of isoinertial dynamometry suggest that practitioners must think carefully about the selection of a valid, safe and time-efficient measure of maximal strength.

The use of the isometric mid-thigh pull offers a method of maximal strength assessment that meets the aforementioned criteria.[12-14] The mid-thigh pull requires participants to stand on a force platform with an immovable bar positioned to correspond with the second-pull clean position, just below the crease of the hip.[15] Participants are then instructed to pull as fast and hard as possible, enabling various kinetic measures to be quantified from ground reaction forces.[16,17] With good reliability[15,18,19] and strong relationships with dynamic actions such as sprinting and jumping,[3,17] the isometric mid-thigh pull presents a useful method for assessing whole-body maximum strength. However, the utility of the method is likely to be limited by the availability of a force platform.[17]

The development of a custom-built isometric mid-thigh pull dynamometer offers a more cost-effective method for the safe and time-efficient measure of maximal strength. However, for practitioners it is important to understand the validity of any new device against the criterion method,[20] whilst it must be capable of differentiating between those of different training status (i.e. construct validity).[21] In a recent study by James et al.,[19] isometric mid-thigh pull performance measured using a strain gauge had good reliability (coefficient of variation = 3.1%) but poor criterion validity when compared against the same exercise conducted on a force platform. In this study, validity was assessed using a relatively small sample size of recreationally active participants (n = 15) and no attempt was made to understand the ability of the simplified apparatus to differentiate peak force capabilities between athletes of different training status (i.e. construct validity). Accordingly, the purpose of this study was twofold: 1) to compare the peak forces obtained in a group of professional rugby league players during the isometric mid-thigh pull between a custom built dynamometer and a force platform (i.e. criterion validity); and 2) to establish the utility of the isometric mid-thigh pull to differentiate muscle strength characteristics between rugby league players of different standards (i.e. construct validity).

Methods

Participants and design

With institutional ethics approval and participant consent, 56 male rugby league players were recruited from two professional clubs and classified as senior professional (n = 33, age 25.3 ± 3.4 years, stature 183.9 ± 6.8 cm, body mass 97.9 ± 9.5 kg) and youth professional (n = 23, age 18.3 ± 1.4 years, stature 179.2 ± 5.2 cm, body mass 86.2 ± 8.2 kg) players. Senior players had completed at least one season training for, and competing in, the Super League competition. Youth consisted of players who were currently playing at Academy level or who had in the last three months graduated to the first team. Data were collected in the pre-season period with all players having at least two years of systematic resistance training experience that involved lower body maximum lifts. After habituation, each player completed two isometric mid-thigh pull strength assessments on the dynamometer and force platform in a randomised cross-over design with a five-minute passive recovery between each effort. All testing was carried out indoors on a hard, non-slip surface.

Procedures

All participants completed a standardised warm up before the mid-thigh pull that comprised of five minutes of dynamic stretching along with two isometric efforts at 50% and 75% of maximal effort.[22] For both measurements, participants were positioned similar to the second pull phase of the power clean, with the bar located mid-way between the knees and hips, knees flexed at ~140 degrees and shoulders over the bar.[23] Based on previous literature, participants were given a 3 second countdown and instructed to pull as fast and hard as possible for 5 seconds, placing emphasis on the rate of force development, which is reported to aid maximal force development.[24]

Dynamometer: A custom-built isometric mid-thigh pull dynamometer was designed and built to include a T.K.K.5402 dynamometer (Takei Scientific Instruments Co. Ltd, Niigata, Japan) sampling at 122 Hz. Briefly, this consisted of a wooden platform (80 x 50 cm) with rubber foot grips (31 x 20 cm), placed shoulder width apart and chain (51 cm) from the dynamometer to a latissimus pulldown bar (120 cm; Decathlon, United Kingdom; see Figure 1b). The chain length was adjusted to allow participants to achieve the position described above. Before pulling, participants applied minimal pre-tension to the chain to avoid any jerking action on initiating the lift. The highest peak force (kgf) from the two attempts was then multiplied by 9.81 (to represent the value in Newtons) and subsequently used for analysis.

Force Platform: The isometric mid-thigh pull was performed using a commercially available portable force platform (HUR Labs, FP4, Tampere, Finland) with a sampling rate of 1200 Hz. The force plate was seated in a customized fixed rack, which enabled adjustments in bar height by 3 cm increments (Figure 1a). Where necessary, smaller adjustments in bar height were made by placing 1 cm wooden boards on the force platform. In such instances the force platform was then re-calibrated before any measurement was performed. Each participant's best trial from two attempts, as determined by the highest peak force (PF) in Newtons (N), was used for analysis.[22]

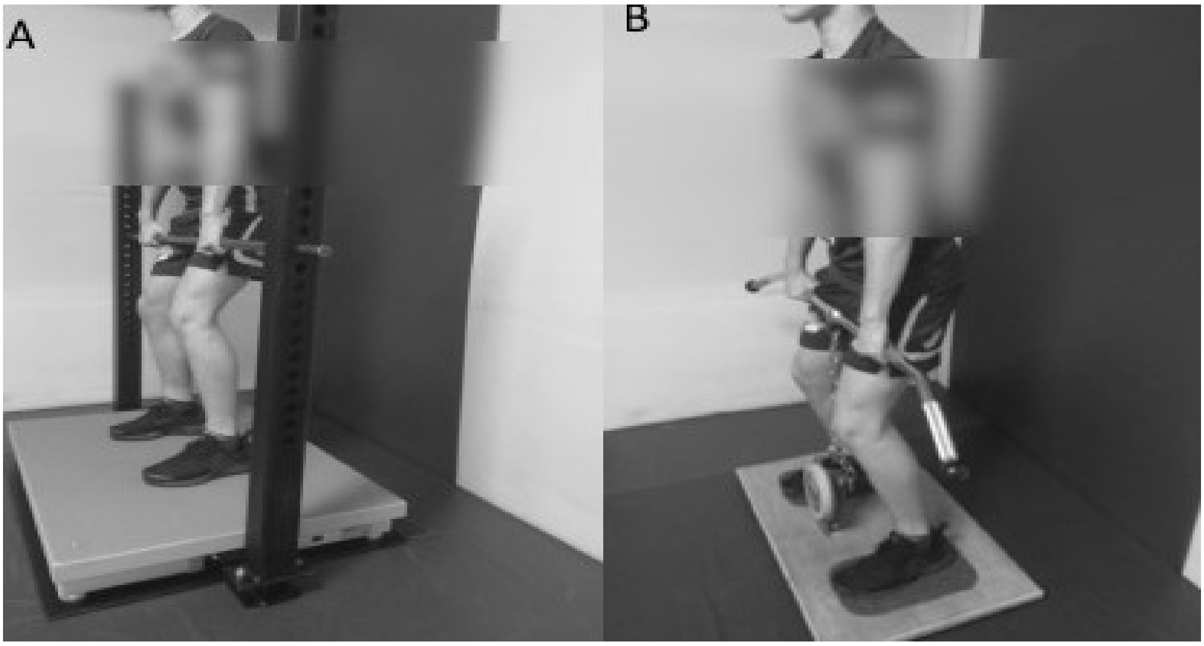

Figure 1. Image of the isometric mid-thihg pull on a force platform (A) and dynamometer (B)

Statistical Analyses

Data were initially checked for normality via the Shapiro-Wilk statistic (P>0.05) before using Pearson product-moment correlations (r-value) to check for heteroscedastic errors and assess the relationship between methods. Paired sample t-tests were used to calculate differences (biases) between means of measurement methods (criterion validity) and followed up using 95% limits of agreement (95% LoA)[25] to quantify the within-subject variation (random error). Effect sizes (ES) and 90% confidence intervals [lower bound – upper bound] were also used to quantify the magnitude of the effect between methods and groups using the following criteria: 0.2, 0.6 and 1.2 for small, moderate and large effects, respectively.[26] Linear regression analysis was used to determine a prediction equation for peak force along with the typical regression statistics (R^2 and SEE). Using an 80/20% split of the sample,[27] we cross-validated the prediction equation and sought to establish that there was minimal shrinkage in the R^2

value relative to the model. This being the case, the full predictive model can be presented. To determine the sensitivity of the IMTP against an analytical goal, an independent *t*-test was used to assess between-group differences in peak force (construct validity) and normalised peak force using ratio (PF/BM) and allometric (PF/BM^{b}) scaling, where PF represents peak force, BM is body mass in kilograms and *b* is a power exponent.[28] Within-session reliability was determined using coefficient of variation (CV) and intraclass correlation coefficient (ICC). Data are reported as mean and standard deviation(s) and analysed using SPSS for Windows (Version 23.0, 2015) and a predesigned spreadsheet.[29]

Results

Within-session reliability revealed CVs of 8.3% and 9.2%, and ICCs of 0.913 and 0.912 for the dynamometer and force platform, respectively. Isometric peak force was significantly underestimated (P < 0.001, ES = -0.53 [-0.85 - -0.21] using the dynamometer compared to the force platform, with 95% of the differences ranging between -556.1 and 130.1 N. However, there was a strong, significant relationship for peak force between the dynamometer and force platform (r = 0.92, P<0.001) (Table 1, Figure 2).

Table 1. Concurrent validity of the dynamometer against the force platform for measuring peak force.

	Dynamometer peak force (N)	Force platform peak force (N)	95% LoA	CV%	Pearson's *r* value
Peak force (N)	2041.0 ± 367.5*	2254.5 ± 435.5	-213.5 ± 342.6	19.3	0.92

*Note: * = significantly lower (P<0.05) than peak force derived from force platform. LoA = limits of agreement. CV% = coefficient of variation.*

Table 2. Overall parameters of the cross-validation prediction model using the dynamometer to estimate peak force (N) derived from the force platform (*n* = 45).

Predictor Variable	Unstandardized coefficient		Standardized coefficient	
	B	Standard Error	Beta	*t*-value
Constant	117.594	161.600		*0.0728*
Dynamometer peak force (N)	1.046	0.079	0.897	*13.302***

*Note: Adjusted R^2 = 0.800; ** = P<0.001.*

Table 3. Cross-validation of predicted and observed force platform peak force (*n* = 11)

	Predicted Peak Force	Force platform peak force (N)	95% LoA	CV%	Adjusted R^2
Peak force (N)	2344.3 ± 319.6	2362.8 ± 388.0	-4.60 ± 352.56	14.73	0.796

*Note: predicted force platform peak force = (1.046 * Dynamometer peak force) + 117.594.*

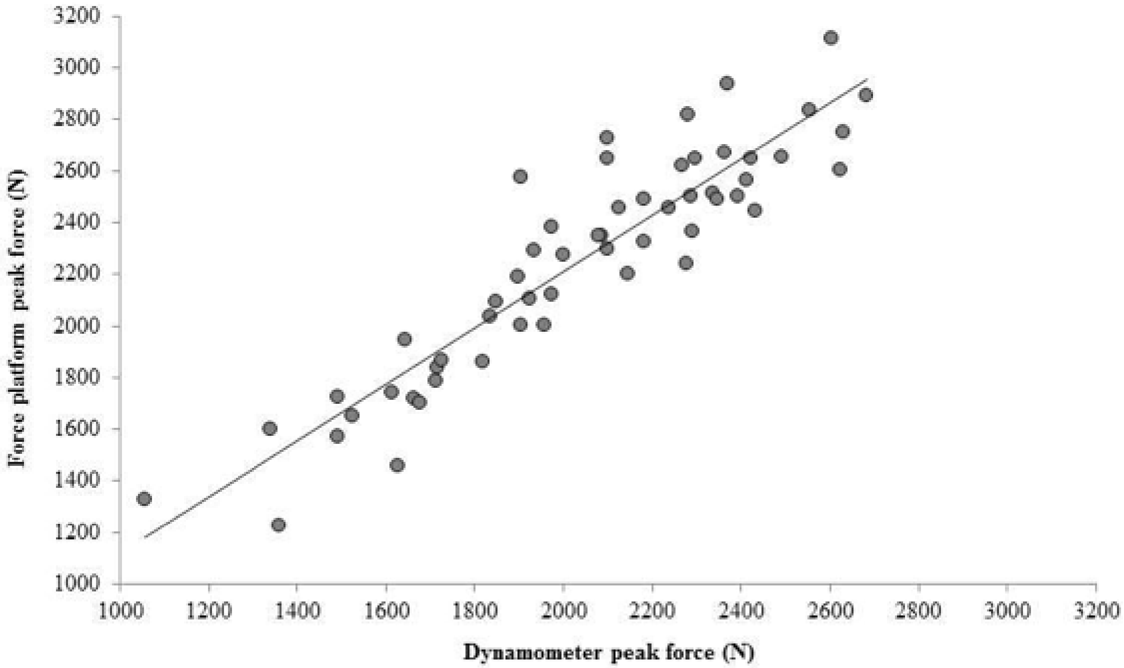

Figure 2. Relationship between the dynamometer and force platform for measuring peak force.

The regression analysis based upon the cross-validation sample (Table 2) revealed that peak force derived from the dynamometer explained 80% (adjusted R^2 = 0.80) of the variance in the dependent variable, yielding the equation: predicted peak force = (1.046 * dynamometer peak force) + 117.594. Cross-validation analysis revealed no significant difference (P = 0.724, ES = 0.05 [-0.26 - 0.36] between the predicted and observed peak force from the force platform, and an adjusted R^2 (79.6%) that represented a shrinkage of 0.4% relative to the cross-validation model (80%, Table 3). Therefore, the predictive power of the model was not substantially changed when applied to a different sample.

The overall regression model (Table 4) revealed that peak force measured on the dynamometer explained 84.2% of the variance in the dependent variable (SEE = 173 N). The equation was: peak force (N) = (1.089*dynamometer peak force) + 31.95.

Peak force was greater for the senior compared to youth professionals using both the force plate (2532.7 ± 242.5 cf. 1855.3 ± 325.1 N, respectively; *t* = 8.93, *P*<0.001, ES = 2.36 [1.96 - 2.76] and the modified dynamometer (2261.2 ± 222.0 cf. 1725.1 ± 298.0 N, respectively; *t* = 7.66, *P*<0.001, ES = 2.04 [1.66 - 2.42]. Due to the large difference in body mass (ES 1.32 [0.98 – 1.66], peak force data were scaled to account for this difference. Senior players generated significantly greater force compared to youth with both ratio (26.07 ± 3.08 cf. 21.58 ± 3.71 N/kg, *t* = 4.936, *P*<0.001, ES = 1.32 [0.98 – 1.66] and allometric scaling (23.44 ± 2.63 cf. 19.46 ± 3.35 $N/kg^{1.02}$, *t* = 4.828, *P*<0.001, ES = 1.32 [0.98 – 1.66] applied. Similarly, peak force was greater for the senior players compared to youth on the dynamometer for ratio (23.25 ± 2.63 cf. 20.04 ± 3.25 N/kg, *t* = 4.069, *P*<0.001, ES = 1.09 [0.76 – 1.42] and allometrically (21.88 ± 2.50 cf. 18.89 ± 3.07 $N/kg^{1.01}$, *t* = 4.01, *P*<0.001, ES = 1.07 [0.74 – 1.40] scaled values.

Table 4. Overall parameters for the prediction model using peak force derived from the dynamometer (N) to estimate force platform peak force (N) (n = 56).

Predictor Variable	Unstandardized coefficient		Standardized coefficient	
	B	Standard Error	Beta	*t*-value
Constant	31.950	131.816		*0.242*
Dynamometer Peak Force (N)	1.089	0.064	0.919	*17.127***

*Note: Adjusted R^2 = 0.842; ** = $P<0.001$.*

Discussion

This study sought to compare the peak force obtained during the isometric mid-thigh pull performed on a customised dynamometer and a force platform in a group of professional rugby league players (i.e. criterion validity). Additionally, comparisons between two playing standards (senior and junior professionals) were made to determine the construct validity of the isometric mid-thigh pull for use with rugby league players. The principle finding of this study was that the isometric mid-thigh pull performed on a custom-built dynamometer underestimated peak force from a force platform as evidenced by the significant difference and small effect size. However, there was a strong relative agreement between both measurement methods. As such, a regression equation was developed that could correct this 'average' underestimation. Finally, the modified dynamometer was able to differentiate peak force between playing standards suggesting it possesses appropriate construct validity in the measurement of muscle function characteristics of senior and youth professional rugby league players.

There was poor agreement between peak force measurements during an isometric mid-thigh pull on the modified dynamometer and the force platform. The mean difference in peak force achieved between the two methods indicated that the modified dynamometer was, on average, -213.5 N lower compared to the force platform. This is consistent with the systematic bias (-229.1 N) between similar apparatus reported by James et al.[19] When the 95% LoA were considered, a player with a peak force of 2000 N measured during an isometric mid-thigh pull using a force platform could, in the worst-case scenario, achieve a value between 1444 and 2129 N using the modified dynamometer. To provide context, this potential error (~685 N) is larger than improvements in peak force derived from an isometric mid-thigh pull after a nine-week maximal strength or power training programme (431-608 N).[30] This means it would be difficult to detect meaningful changes in mid-thigh pull performance when using the modified dynamometer and, therefore, when small-to-moderate changes are expected, practitioners might consider using a regression equation or force platform.

The underestimation in peak force observed in the present study might be explained by the more open-chain design of the modified dynamometer compared to that of the force platform. During the force platform trials, peak ground reaction force was measured through the feet in contact with the force platform and force applied vertically in a single plane. In contrast, the modified dynamometer required participants to 'pull' vertically on a bar anchored centrally, which due to its design had a large degree of anterior-posterior and medio-lateral movement. It is possible that this movement allowed participants lean back into the pull, resulting in force being applied outside of the vertical axis.[19] It is also possible that the superior sampling frequency of the force platform compared to the modified dynamometer (1200 *cf.* 122 Hz, respectively) influenced the precision of the peak force measurements.[15]

To correct for the underestimation of peak force using the modified dynamometer, we have developed a regression equation that reduces the difference from the force platform to within mean values of ~4.6 N. Therefore, when a comparison between methods is necessary, this equation can be applied to data collected from the modified dynamometer when using a similar sample to that used in this study. However, practitioners should note that there might be some error in this estimate of ~173 N in individual cases, owing to some of the variance in force platform performance not being explained by performance using the modified dynamometer.

In this study, players of a higher standard, who are deemed to be stronger from more extensive resistance training exposure,[6] performed better on the isometric mid-thigh pull using both methods. More specifically, peak force measured on the modified dynamometer for senior professional rugby league players was 31% higher than that of youth professionals, similar to the difference of ~36% according to the force platform. Furthermore, our results indicated that this large difference in peak force was irrespective of differences in body mass. After applying both ratio and allometric scaling, the results indicated that senior players out-performed youth players regardless of body mass, suggesting training history is an important factor when assessing peak force. As such, the modified dynamometer mid-thigh pull is sufficiently sensitive to be used to classify the strength capabilities of professional rugby league players of different standards and training histories.

Practical Applications

A criterion measure of peak force during an isometric mid-thigh pull cannot be measured from a modified dynamometer. This notwithstanding, the dynamometer is capable of distinguishing differences in muscle function between more and less experienced rugby league players. For those practitioners who require more accurate measures of peak force from isometric mid-high pull, they might choose to use the regression equation provided. It is important to note that the prediction equation for peak force is specific to rugby league players and caution should be taken when applying this to other populations. Strength and conditioning coaches who wish to measure maximal strength when profiling rugby players might adopt this safe, cost-effective and valid apparatus.

Conclusion

The current study investigated the criterion and construct validity of a modified dynamometer for the assessment of isometric mid-thigh pull strength. Where practitioners are required to profile players (i.e. talent identification), the use of a modified dynamometer can be used to differentiate between academy and first-grade professional rugby league players. Additionally, the regression equation provided can allow practitioners to detect training-induced changes in whole-body strength, albeit they should be cognisant that small changes are likely to go undetected, and in such cases, a force platform should be used.

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Appendix 13. The influence of preseason training phase and training load on body composition and its relationship with physical characteristics in professional junior rugby league players.

Introduction

Rugby league is a high-intensity intermittent collision sport, requiring players to possess well-developed speed, strength, power and intermittent running capacity to cope with the demands of training and match-play.[18] Such physical qualities are routinely measured and used to ensure players are conditioned appropriately to perform rugby-specific skills,[12] evaluate adaptation to training programmes,[24] talent identification[18] and monitoring the development of players.[30] Whilst we recognise that performance and success in rugby league might be influenced by the complex interaction of an individual's and team's technical and tactical characteristics, much focus has been given to the anthropometric and physical qualities of players.[18]

Body composition is of particular interest for both practitioners and researchers, as changes in criterion (e.g. DXA) or predictive (e.g. skinfolds) measures of body fat percentage (%BF), fat mass (FM), fat free mass (FFM) and lean mass (LM) can be indicative of adaptation to training,[3,12] physical development[21,30] and a player's dietary intake.[28] Studies examining body composition of rugby league players have reported differences between playing positions,[23] performance standards[19] and phase of the competitive season.[13,15] Hit-up forwards are heavier, have greater LM, FM and %BF compared to outside backs and adjustable, with small differences between the latter positions.[23] Super League players typically have lower %BF and FM, with greater total, leg and trunk LM compared to Championship players.[19] Seasonal variation also indicates that FM increases and LM decreases during the latter stages of the season.[15] These findings highlight the importance of body composition in rugby league and support the notion that it should be regularly monitored across the season whilst considering playing position and training status.

To develop anthropometric and physical qualities, strength and conditioning (S&C) practices are a key component in rugby league, particularly during the preseason period, where S&C coaches have 12-13 weeks to prepare players for competition. Once competition commences, the focus is largely placed on recovery, technical performance and tactical awareness, resulting in a decrease in training volume.[11] To date, several studies have explored the preseason changes in anthropometric and physical qualities in rugby league,[5,11,24] suggesting this period is effective for reducing fat mass (-0.6 kg) and percentage body fat (-1.0%), and promoting muscle mass (0.7 kg) in rugby league players.[24] Furthermore, Comfort et al.[5] observed improvements in sprint times across 5, 10 and 20 m as well as greater relative strength (1.78 ± 0.27 *cf.* 2.05 ± 0.21 $kg \cdot kg^{-1}$). These results concur with those of Argus et al.[1] who observed reductions in skinfold thickness and FM, and a small increase in FFM after only 6 weeks of rugby union preseason training, which coincided with increases in bench press and box squat. Whilst comparisons between codes should be made with caution, these findings suggest that preseason training ranging from 6 to 13 weeks is effective for promoting changes in body composition.

Typically, the preseason comprises 3-4 periodised phases of varying length.[24] Each phase will vary depending on the coach, though typically focus on aerobic and anaerobic conditioning, sprinting mechanics, muscular strength and power, flexibility, and rugby-specific skills.[24,32] Whilst previous research has reported the pre- to post-preseason change in body composition, to our knowledge no one has reported the change in relation to the training phase and training load within each periodised block. How these changes in body composition and training load relate to changes in physical qualities is of interest to support future programming and enable sports nutritionist and players to periodise energy and macronutrient intake.[4] Therefore, the aims of this study were threefold: 1). To determine the effects of training phase and training load on group and individual changes in body composition, 2). To explore the individual variability of the change in body composition, and 3). To assess the relationship between the overall changes in body composition, total training load and measures of physical qualities.

Methods

Participants

With institutional ethics approval, 16 academy rugby league players (forwards = 8; backs = 8) from a single professional club playing in the Under-19s Super League competition (age, 17.2 ± 0.7 years; stature = 179.9 ± 4.9 cm; body mass 88.5 ± 10.1 kg) participated in this study. Players were familiar with all testing procedures and were informed of the benefits and risks associated with this study before providing written informed consent and completing a pre-test health questionnaire. Parental assent was obtained for participants <18 years old. Only players free of injury during the whole preseason period, as confirmed by the club's medical team, were included.

Study design

A repeated measures design was used to investigate the changes in body mass, skinfold thickness, %BF, FM, FFM and LM as well as measures of physical qualities. Training load (TL) was recorded for every session and used to assess the relationship between TL and changes in body composition with the change in physical qualities. The preseason training was prescribed by the club's strength and conditioning coach and was divided into three phases (phase 1 = 5 weeks, phase 2 = 4 weeks, phase 3 = 4 weeks + 1-week taper), with the end of phase 1 and start of phase 2 interspersed by a 10-day rest period. A 'typical' week is presented in Table 1. Assessments of body composition were taken before and after each training phase and physical qualities assessed the week before preseason training started and one week before their first competitive fixture. All physical qualities were measured on the club's own artificial pitch by the same researcher.

Table 1. Typical training week for each phase of the preseason period.

	Monday	Tuesday	Thursday	Saturday
Training Phase 1	Whole-body resistance training	Aerobic conditioning + rugby training	Aerobic conditioning + rugby training	Aerobic conditioning + rugby training
Training Phase 2	Aerobic + Anaerobic conditioning	Lower-body resistance training + rugby	Upper-body resistance training + conditioning	Lower-body resistance training + rugby training
Training Phase 3	Lower-body resistance + wrestle + rugby	Upper-body resistance + aerobic conditioning	Lower-body strength + aerobic conditioning + rugby	Upper-body resistance + rugby training.

Note: Resistance training: typical exercises included bench press, box squat, trap bar deadlift and weighted carries.
Aerobic conditioning: comprised maximal aerobic speed training (100-130% based on 2km time trial average velocity) and small-sided games.
Anaerobic conditioning: involved repeated sprints efforts incorporating shuttles, contact efforts and getting up from a prone position.
Rugby training typically comprised attacking and defensive plays.

Methodology

Body Composition

An International Society for the Advancement of Kinanthropometry (ISAK) protocol was used and the same assessor conducted all measurements (intra-rater reliability CV = 0.3-1.3%). Stretch stature was measured using a portable stadiometer (Seca, Leicester Height Measure, Hamburg, Germany) to the nearest 0.1 cm, and body mass (Seca, 813, Hamburg, Germany) to the nearest 0.1 kg. Skinfold thickness was assessed using Harpenden calipers (Harpenden, Burgess Hill, UK) on the right side of the body and included seven sites (triceps, subscapular, biceps, supraspinale, abdominal, thigh, calf). All measures were taken in duplicate with the mean value used, unless the differences exceeded 5%, whereby a third measurement was taken and the median value used. Body density was calculated[33] before the following equation was applied to covert body density to %BF: %BF = (495/body density)-450.[25] Fat free mass (body mass – FM) was then calculated using the equation: FFM = body mass - (body mass * %BF)/100. Lean mass index was also used to quantify proportional changes in LM using the equation M/S^x; where M is the log transformed body mass in kilograms, S is log transformed skinfold thickness in millimetres and x represents an exponent for rugby union backs (0.14).[26]

Sprint performance and momentum

Sprint performance was measured using electronic timing gates (Brower, Speedtrap 2, Brower, Utah, USA) positioned at 0, 10 and 20 m. Participants began each sprint from a two-point athletic stance with their driving foot placed 30 cm behind the start line. Participants performed two maximal 20 m sprints recorded to the nearest 0.01 s with two minutes recovery. The best 10 and 20 m sprint times were used for analysis

(CV = 4.2 and 3.6%, respectively). Momentum was calculated by multiplying body mass by mean velocity (distance / time) over the best 10 and 20 m times.[6] Sprint performance and momentum over these distances are reported to be reliable (Study 1).

Change of direction

Change of direction (CoD) performance was measured using electronic timing gates (Brower, speedtrap 2, Brower, Utah, USA) placed 150 cm apart and at a height of 90 cm, and required participants to complete two trials (left and right) consisting of different cutting manoeuvres over a 20 x 5 m course with markers position at 0, 5, 15 and 20 m (see Study 1). Participants started when ready from a two-point athletic stance with their driving foot placed 30 cm behind the start line and the times from the left and right were combined and used for analysis (CV = 2.5%) (Study 1).

Countermovement Jump

Participants completed two CMJ with their hands placed on the hips and two minutes recovery between jumps. Participants started upright before flexing at the knee to a self-selected depth and then extending into the jump striving for maximal height keeping their legs straight throughout. Jump height was recorded using a jump mat (Just Jump System, Probotics, Huntsville, Alabama, USA) and corrected (Appendix 11) before peak height was used for analysis (CV = 5.9%) (Study 1).

Medicine ball throw

To measure whole-body power, participants began standing upright with a medicine ball (dimensions: 4 kg, 21.5 cm diameter) above their head before lowering the ball towards their chest, squatting down to a self-selected depth and extending up onto their toes pushing the ball as far as possible. Feet remained shoulder width apart, stationary and behind a line that determined the start of the measurement. The distance was measured to the nearest centimetre using a tape measure from the start line to the rear of the ball's initial impression on the 3G surface. A trial was not recorded if the participant stepped into the pass, jumped or if the ball landed outside of the measuring area and, in such cases, an additional trial was completed. Participants completed two trials separated by 2-minutes recovery with the furthest distance used for analysis (CV = 9.0%; Study 1).

Prone Yo-Yo Intermittent Recovery Test Level 1

The prone Yo-Yo IR1 was used to measure rugby-specific high-intensity intermittent running ability and required participants to complete as many 40 m (2 x 20 m) shuttles as possible with a 10 s active recovery (walking) between shuttles. Running speed for the test commenced at 10 $km \cdot h^{-1}$ and increased 0.5 $km \cdot h^{-1}$ approximately every 60 s to the point at which the participants could no longer maintain the required running speed. Unlike the traditional Yo-Yo IR1, participants were required to start each 40 m shuttle in a prone position with their head behind the start line and legs straight, and were allowed two practice shuttles before starting the test. The final distance achieved was recorded after the second failed attempt to meet the start/finish line in the allocated time (CV = 9.9%; Study 1).

Training Load

Thirty minutes after training, away from teammates and coaches, participants were asked to provide a rating of perceived exertion (RPE) for each activity (i.e. gym, skills, conditioning) using 10-point scale, which was subsequently multiplied by duration in minutes to provide a measure of training load (sRPE).[10]

Statistical analysis

Data are presented as mean ± standard deviation (SD). Magnitude-based inferences (MBI) and effect sizes with 90% confidence limits were used, with effect sizes calculated as the difference between trials divided by the pooled SD for all assessments. This approach was applied to the body composition data to assess the pre-to-post change within each training phase and overall changes (pre-phase 1 to post-phase 3) in body composition measures and physical qualities. Threshold values for effect sizes were: 0.0-0.2, *trivial*; 0.2-0.6, *small*; 0.6-1.2, *moderate*; 1.2-2.0, *large*; >2.0, *very large*. Threshold probabilities for a mechanistic effect based on the 90% confidence limits were: 25-75% *possibly*, 75-95% *likely*, 95-99% *very likely* and > 99.5 *most likely*.[2] Effects with confidence limits spanning a likely small positive or negative change were classified as *unclear*. To determine if a change in body composition was practically meaningful when considering the researcher's reliability, the smallest worthwhile changes (0.2 * pooled SD) was added to the coefficient of variations [(TE / grand mean) x 100] to give 75% confidence likely change. To ascertain the relationship between the overall (i.e. pre-phase 1 to post-phase 3) change in body composition measures, TL and changes in physical qualities, Pearson's correlation (*r*) was used with the following criteria applied: < 0.1, *trivial*; >0.1-0.3, *small*; >0.3-0.5, *moderate*; >0.5-0.7, *large*; >0.7-0.9, *very large*; and >0.9-1.0, *almost perfect* and the coefficient of determination included. Statistical analysis was conducted using a predesigned spreadsheet for comparing means[16] and correlations coefficient and coefficient of determination.[17]

Results

Players' completed 90 ± 7% of total sessions during the preseason period. Phase 1 consisted of 37 ± 1 sessions (14 ± 1 resistance, 12 ± 2 conditioning and 11 ± 1 rugby) and an accumulated TL of 11018 ± 1130 AU (4288 ± 517 resistance, 4206 ± 513 conditioning and 2525 ± 490 AU rugby). Phase 2 included 26 ± 6 sessions (11 ± 2 resistance, 7 ± 2 conditioning and 8 ± 2 rugby) and resulted in a total TL of 7493 ± 1322 AU (3126 ± 658 resistance, 1926 ± 332 conditioning, 2441 ± 521 AU rugby). The final phase consisted of 25 ± 2 sessions (10 ± 2 resistance, 4 ± 1 conditioning and 11 ± 2 rugby) and an accumulated TL of 4159 ± 839 AU (1788 ± 373 resistance, 331 ± 111 conditioning, 2051 ± 482 AU rugby).

Table 2. Mean body composition of professional junior rugby league players over three preseason phases.

Data are presented as mean ± SD, with effect sizes and magnitude-based inference used to calculate the change between pre and post for

	Training Phase 1		Training Phase 2		Training Phase 3		Phase 1	Phase 2	Phase 3	Overall
	Pre	Post	Pre	Post	Pre	Post	ES ± 90% CI	ES ± 90% CI	ES ± 90% CI	ES ± 90% CI
Body mass (kg)	88.5 ± 10.1	87.9 ± 8.8	88.0 ± 9.1	87.4 ± 9.1	87.4 ± 9.1	87.4 ± 9.1	-0.05 ± 0.09 *Most likely* ↔	-0.08 ± 0.05 *Most likely* ↔	0.01 ± 0.06 *Most likely* ↔	-0.10 ± 0.14 *Likely* ↔
Skinfolds thickness (mm)	88.1 ± 25.3	78.2 ± 24.3	71.9 ± 20.0	68.2 ± 18.9	68.2 ± 18.9	67.2 ± 18.6	-0.46 ± 0.09 *Most likely* ↓	-0.22 ± 0.08 *Possibly* ↓	-0.05 ± 0.12 *Very likely* ↔	-1.00 ± 0.22 *Most likely* ↓
Body fat (%)	15.2 ± 4.5	12.2 ± 3.8	12.1 ± 4.5	12.0 ± 3.2	12.0 ± 3.3	11.8 ± 3.3	-0.85 ± 0.14 *Most likely* ↓	-0.21 ± 0.08 *Possibly* ↓	-0.05 ± 0.12 *Very likely* ↔	-0.94 ± 0.21 *Most likely* ↓
Fat mass (kg)	13.9 ± 5.9	11.0 ± 47	11.3 ± 4.5	10.7 ± 4.2	10.7 ± 4.2	10.6 ± 4.2	-0.64 ± 0.10 *Most likely* ↓	-0.18 ± 0.06 *Possibly* ↓	-0.03 ± 0.10 *Very likely* ↔	-0.73 ± 0.20 *Most likely* ↓
Fat free mass (kg)	74.6 ± 5.4	76.8 ± 5.4	76.7 ± 5.7	76.8 ± 5.8	76.8 ± 5.8	76.9 ± 5.7	0.39 ± 0.10 *Most likely* ↑	0.02 ± 0.07 *Most likely* ↔	0.03 ± 0.06 *Most likely* ↔	0.40 ± 0.10 *Most likely* ↑
Lean mass index ($mm \cdot kg^{-0.14}$)	37.9 ± 2.7	38.3 ± 2.4	38.7 ± 2.5	39.1 ± 2.6	39.1 ± 2.6	38.8 ± 2.4	0.14 ± 0.11 *Likely* ↔	0.16 ± 0.07 *Likely* ↔	0.03 ± 0.06 *Most likely* ↔	0.31 ± 0.12 *Likely* ↑

phase 1, 2, 3 and the overall change (pre-phase 1 to post-phase 3). ↓/↑/↔ represent an increase, decrease or trivial change, respectively.

Mean body composition before and after each training phase as well as the whole period are presented in Table 2. Individual changes in body mass, skinfold thickness, %BF, FM, FFM and LM are presented for each training phase in Figure 1 and 2.

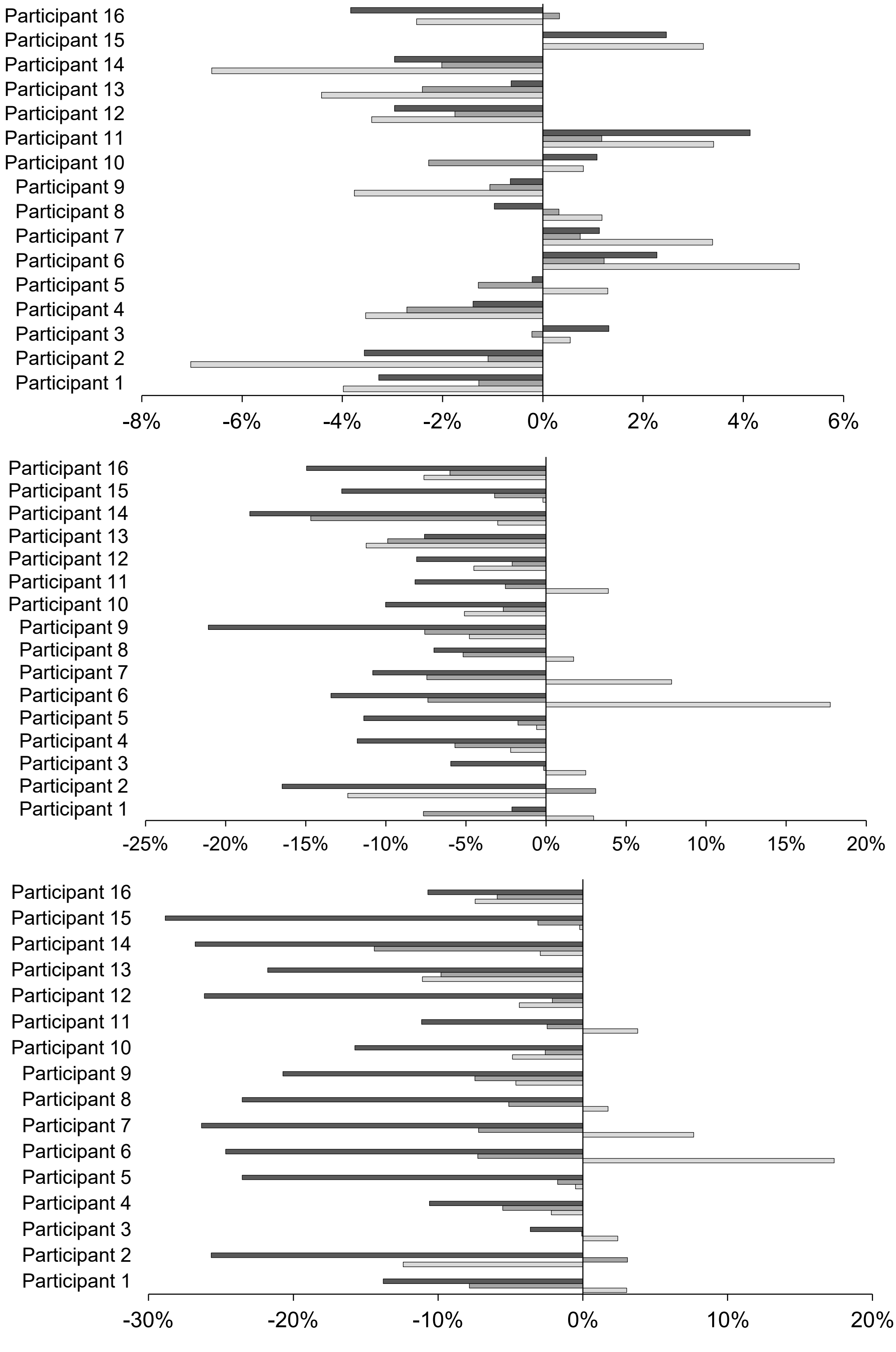


Figure 1. Individual percentage change during training phase 1 (dark grey), 2 (grey) and 3 (light grey) body mass (A), skinfold thickness (B) and body fat percentage (C). The shaded area represents the SWC combined with TE (%) to provide a meaningful change with 75% confidence. Scores inside the shaded area are consider unclear.

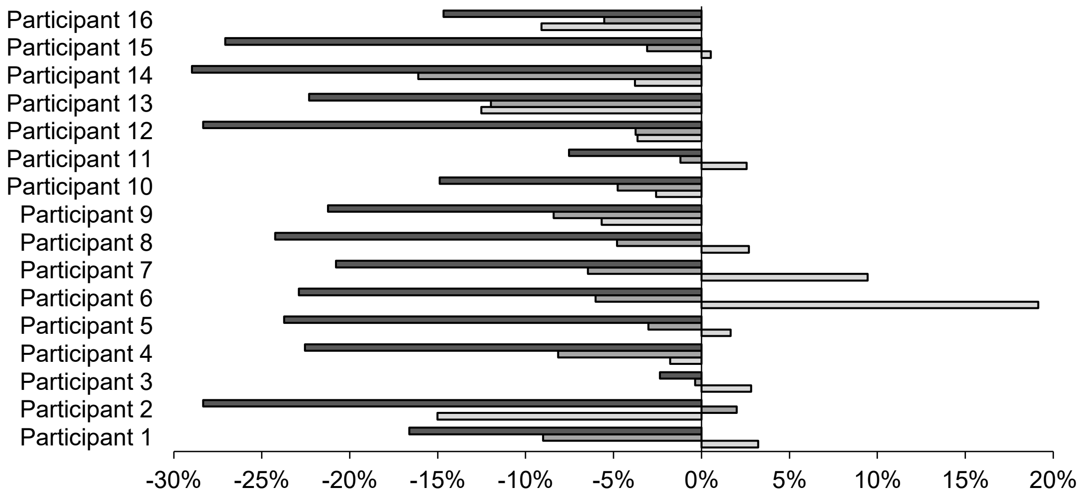
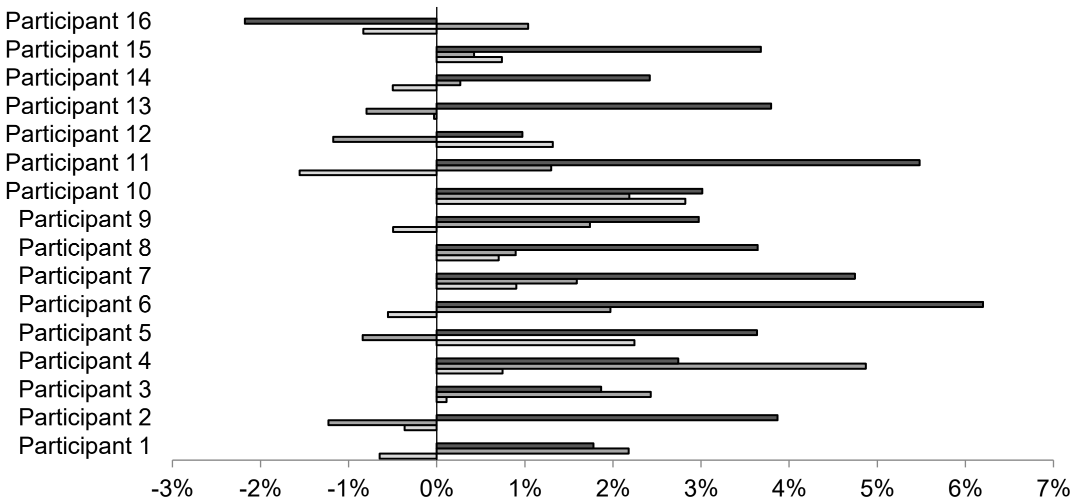
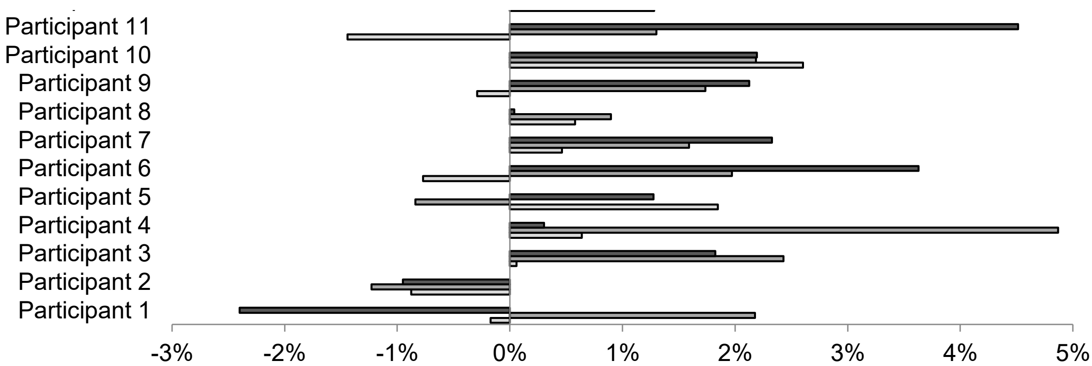


Figure 2. Individual percentage change during training phase 1 (dark grey), 2 (grey) and 3 (light grey) fat mass (A), fat free mass (B) and lean mass index (C). The shaded area represents the SWC combined with TE (%) to provide a meaningful change with 75% confidence. Scores inside the shaded area are consider unclear.





Changes in 10- and 20 m sprint time over the preseason period were *unclear.* Ten and twenty-metre momentum were *possibly* lower and of trivial and small magnitude, respectively. A small to moderate effect was observed for CMJ, medicine ball throw and prone Yo-Yo IR1 scores, which were considered *very* to *most likely* higher after the preseason period. Change of direction time was *very likely* lower and of a small magnitude after the preseason period (Table 3).

Table 3. Changes in physical qualities before and after the preseason period.

	Before	After	ES ± 90% CI
10 m sprint (s)	1.79 ± 0.08	1.80 ± 0.11	0.16 ± 0.43
	(1.67 – 1.98)	(1.65 – 2.01)	*Unclear*
20 m sprint (s)	3.06 ± 0.12	3.07 ± 0.11	0.08 ± 0.27
	(2.91 – 3.39)	(2.90 – 3.40)	*Unclear*
10 m momentum (kg·m·s^{-1})	493.2 ± 52.1	484.3 ± 51.1	-0.17 ± 0.22
	(413.0 – 600.5)	(391.4 – 562.2)	*Possibly* ↓
20 m momentum (kg·m·s^{-1})	577.6 ± 59.1	563.0 ± 57.9	-0.25 ± 0.17
	(489.5 – 692.7)	(460.3 – 656.8)	*Possibly* ↓
CMJ (cm)	34.7 ± 5.9	38.3 ± 5.1	0.57 ± 0.24
	(23.1 – 44.6)	(30.5 – 48.3)	*Very likely* ↑
Change of direction (s)	20.33 ± 0.69	19.99 ± 0.45	-0.50 ± 0.28
	(19.43 – 22.29)	(19.55 – 21.32)	*Very likely* ↓
Medicine ball throw (m)	6.8 ± 0.76	7.3 ± 0.8	0.59 ± 0.31
	(5.4 – 8.4)	(5.4 – 8.8)	*Very likely* ↑
Prone Yo-Yo IR1 (m)	638 ± 192	770 ± 223	0.64 ± 0.23
	(360 – 1000)	(440 – 1200)	*Most likely* ↑

Data are presented as mean ± SD (range), with effect sizes and magnitude-based inference used to calculate the change between pre- and post-measures of physical qualities. The arrows (↓/↑) represent the direction of change.

The correlation coefficient and coefficient of determinations between changes in body composition and TL with changes in physical qualities are presented in Table 4.

Table 4. Correlation coefficient (r) and coefficient of determination (R^2) between changes in body composition, training load and the change in physical qualities over a whole preseason period in professional junior rugby league players.

	Physical qualities							
	Δ10 m (s)	Δ20 m (s)	Δ10 m Momentum (kg·m·s^{-1})	Δ20 m Momentum (kg·m·s^{-1})	ΔCMJ (cm)	ΔChange of Direction (s)	ΔMedicine ball throw (m)	ΔProne Yo-Yo IR1 (m)
ΔBody mass (kg)	0.083	0.195	0.553^{M}	0.624^{M}	0.288	0.555^{M}	0.251	-0.260
	(0.007)	(0.038)	(0.306)	(0.389)	(0.083)	(0.329)	(0.063)	(0.068)
ΔSUM7 (mm)	0.279	0.377^{S}	0.354^{S}	0.446^{S}	0.380^{S}	0.439^{S}	0.215	-0.375^{S}
	(0.078)	(0.142)	(0.125)	(0.199)	(0.145)	(0.193)	(0.046)	(0.141)
ΔBF (%)	0.318^{S}	0.354^{S}	0.274	0.347^{S}	0.365^{S}	0.499^{S}	0.250	-0.354^{S}
	(0.101)	(0.127)	(0.075)	(0.121)	(0.133)	(0.249)	(0.062)	(0.126)
ΔFM (kg)	0.165	0.287	0.471^{S}	0.525^{M}	0.295	0.483^{S}	0.167	-0.346^{S}
	(0.027)	(0.082)	(0.222)	(0.276)	(0.087)	(0.233)	(0.028)	(0.132)
ΔFFM (kg)	-0.078	-0.024	0.472^{S}	0.546^{M}	0.142	0.513^{M}	0.295	0.047
	(0.006)	(0.001)	(0.223)	(0.296)	(0.020)	(0.264)	(0.087)	(0.002)
ΔLMI (mm·kg$^{-0.14}$)	-0.102	-0.029	0.614^{M}	0.664^{M}	0.154	0.651^{M}	0.226	0.095
	(0.010)	(0.0010	(0.377)	(0.441)	(0.024)	(0.424)	(0.051)	(0.009)
Resistance TL	-0.522^{M}	-0.485^{S}	0.119	0.013	0.507^{M}	0.424^{S}	0.403^{S}	0.044
	(0.273)	(0.236)	(0.014)	(0.000)	(0.257)	(0.179)	(0.162)	(0.002)
Conditioning TL	-0.471^{S}	-0.648^{M}	0.512^{M}	0.527^{M}	0.187	0.141	0.026	0.011
	(0.222)	(0.419)	(0.263)	(0.278)	(0.035)	(0.020)	(0.001)	(0.000)
Skills TL	-0.713^{L}	-0.786^{L}	0.349^{S}	0.268	0.596^{M}	0.195	0.218	0.108
	(0.509)	(0.618)	(0.122)	(0.072)	(0.356)	(0.038)	(0.048)	(0.012)
Total TL	-0.698^{M}	-0.767^{L}	0.364^{S}	0.285	0.553^{M}	0.324	0.290	0.071
	(0.488)	(0.589)	(0.133)	(0.081)	(0.306)	(0.105)	(0.084)	(0.005)

Note: S, M, L indicated a small, moderate or large correlation between variables, respectively. Training load (TL) = sRPE x duration.

Discussion

This study sought to determine the changes in body composition in relation to training phase and TL, and establish if a relationship existed between body composition and TL with changes in physical qualities over the preseason period. The principle findings were that preseason training phase influenced the change in body composition, with greater changes observed during phase 1 when training load was highest. Results also indicated large individual variability in changes of body composition and that these changes were correlated with the change in physical qualities.

Mean data revealed that changes in total body mass across each phase and the entire preseason were *most likely trivial,* which might be explained by the contrasting changes in FM and FFM and the inclusion of forward and backs. For example, Morgan & Callister[24] observed a 0.9 kg increase in body mass for rugby league backs, whereas forwards reported a reduction of 0.3 kg during a 14-week preseason period. However, it is important to acknowledge the 'individual' when interpreting such data as demonstrated in phase one where the percentage change in body mass ranged from -3.8% to 4.1%. Interestingly, the results show that the direction of change for body mass was, for the most part, consistent for each participant (i.e. if they increased in body mass during phase 1, they did for all phases). This possibly indicates that the participants' nutritional intake remained stable across the preseason period regardless of TL and has important implications for those players who need to adjust their energy intake to increase/decrease body mass to optimize performance and reduce injury risk.[28]

A reduction in skinfold thickness was observed after phase 1 and 2 but not phase 3. Over the entire preseason, a moderate change was observed in skinfold thickness reaffirming work of Bradley et al.[3] and Morgan and Callister[24] in rugby union and rugby league, respectively. At the individual level, our results indicate that phase 1 and 2, both of which had the highest TL, elicited *most likely* reductions in skinfold thickness, though during phase 3 the changes was somewhat more variable with some individuals increasing their skinfold thickness by 1.3 to 18.3%. Furthermore, the mean absolute and relative body fat were comparable to that reported for Super League players,[19,23] though it is important to recognise the methodological differences between studies. The overall change in %BF (-3.4%) and FM (-3.3 kg) were larger than that previously observed in rugby union[1,3,27] and rugby league[24] players, and might reflect the longer preseason period and large emphasis on conditioning during phase 1. This finding might also be explained by the training age of the participants as it is known that chronological age, biological maturity and training experience can influence the magnitude of adaptation observed in youth rugby league players.[29] Almost all players continued to reduce their body fat during phase 2 potentially owing to the higher TL, though changes during phase 3 were considered trivial. Over a competitive season it has been reported that %BF and FM increases towards the end of the season due to a reduced TL.[13,15] Our results suggest that some individuals increased body fat when TL was reduced towards the end of preseason. In these situations, it is essential players and staff are aware of the energy requirements for each individual to ensure optimum performance during different stages of the preseason period as an increase in %BF and FM is likely to be detrimental to rugby performance.[13,15,20]

Given the physicality of rugby league and the requirements to dominate an opponent during a tackle, increasing lean mass is a key focus during the preseason period.[15] The assessment of whole body or regional LM is impractical given it requires access to expensive and sophisticated equipment (i.e. DXA) that is not readily available in the applied setting. As such, the use of skinfold measurements and predictive equations for fat free mass and lean mass index has been used and relate ($r = 0.97$ and $r = 0.97$, respectively) to criterion measures of FFM.[7] Our results indicate a greater FFM compared to adolescent rugby union players[27] and semi-professional rugby league players[24] but lower than professional rugby union players.[3,24] Over the preseason period, FFM increased by 2.3 kg on average, with *most likely* increases occurring during phase 1. However, assessing the individual responses, one participant decreased FFM by approximately 2%, suggesting further training or nutritional support (i.e. protein consumption) might be required. This is particularly pertinent in light of the poor nutritional knowledge amongst rugby players.[31] Responses during phase 2 and 3 were considered *most likely trivial* and demonstrated large inter-participant variability. Lean mass index represents the changes in body mass adjusted for changes in skinfold thickness and provides some insight into an individual's LM status. Our results indicate that mean LM increased by 0.8 kg over the preseason period, reaffirming existing observations of 0.8 and 0.7 kg increases in lean mass in rugby league forwards and backs, respectively, over a similar period.[24] Furthermore, the percentage change observed in this study (~2.4%) is consistent with that recommended by Jones et al.[20] to stay in positive balance after consideration for the 1-2% loss over a competitive season.[13,15] However, our results suggest that some players might be approaching the season sub-optimally given the association LM has with several physical qualities; and therefore, nutrition, TL and the contents of each training phase requires consideration in order to maximise performance and reduce injury risk.

Changes in 10- and 20 m sprint times were considered *unclear* between the two assessments and agree with Weakley et al.[32] who observed trivial changes in rugby union players sprint time after a 12-week preseason period. That body mass was lower after preseason likely explains the *possibly* lower 10- and 20 m momentum scores, though the magnitude of change was considered trivial and small, respectively. Trivial to small correlations existed between changes in body composition and sprint time whereas, small to large correlations were observed with TL and changes in sprint time. CMJ height was *very likely* higher after the preseason period, which is agreement with previous research.[27,32] Further, moderate correlations were observed between resistance, skills and total TL with changes in CMJ height. Similarly, Weakley et al.[32] reported *very large* correlations between the percentage change in CMJ height and total TL, supporting the notion that practitioners should ensure sufficient TL is provided through resistance training and rugby-specific skills (i.e. wrestling) to develop lower-body power. Medicine ball throw performance was *most likely* higher after preseason and was positively correlated with resistance TL, which agrees with Weakley et al.[32] Change of direction times were *very likely* lower after the preseason period with small to moderate positive correlations between changes in some measures of body composition. A *most likely* improvement in prone Yo-Yo IR1 performance was elicited over the preseason period and was higher than the required change for 75% confidence previously reported (Study 1). Small negative correlations were observed for changes in body mass, skinfold thickness, FM and %BF with the change in prone Yo-Yo IR1 distance, indicating that body mass and excessive body fat might be detrimental for high-intensity intermittent running. These results concur previous work in soccer where a relationship between sRPE-TL and time to exhaustion during the Montreal Track test, lower-body power and sprint performance was observed in junior soccer players.[14] In all, the result indicated that changes in body composition over the entire preseason period as well as training load accumulated can influence the anthropometric and physical qualities of youth rugby league players.

Our results support the notion that TL and the change in body composition can influence physical qualities in rugby league players, though there are some limitations. Dietary intake was not monitored in this study and a single club was used. Therefore, future research might determine the nutritional intake of rugby league players across the preseason period using multiple clubs and explore how this influences measures of body composition. Whilst we have provided the coefficient of determination between variables, future analysis might use a larger sample size and consider step-wise regression to understand the extent to which the change in measures of physical qualities can be explained by changes in body composition and TL. Finally, this study used sRPE to determine training load, which might not fully reflect the psychophysiological construct associated with certain activities and therefore more detailed analyses combining microtechnology and differential RPE to quantify training load[22] might be considered in the future.

Conclusion

For the first time, we provide evidence that training phase and TL is important to consider when assessing body composition during the preseason period in rugby league players. These findings have practical implications for strength and conditioning staff working to develop the physical attributes of rugby league players, and suggest that coaches should provide sufficient TL to optimise body composition and monitor player’s dietary intake during the preseason period, particularly during the latter stages. These results support previous work and show large inter-participant variability and therefore suggest that practitioners within rugby league should consider the ‘individual’ rather than group means. Finally, given the influence changes in body composition and TL can have on improvements in physical qualities over a specified training phase, optimising body composition and providing sufficient TL should be a priority for practitioners.

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Appendix 14. Coaches' and players' attitudes towards performance testing and the influence of spectators on physical performance: a mixed-methods case study of an elite rugby league academy.

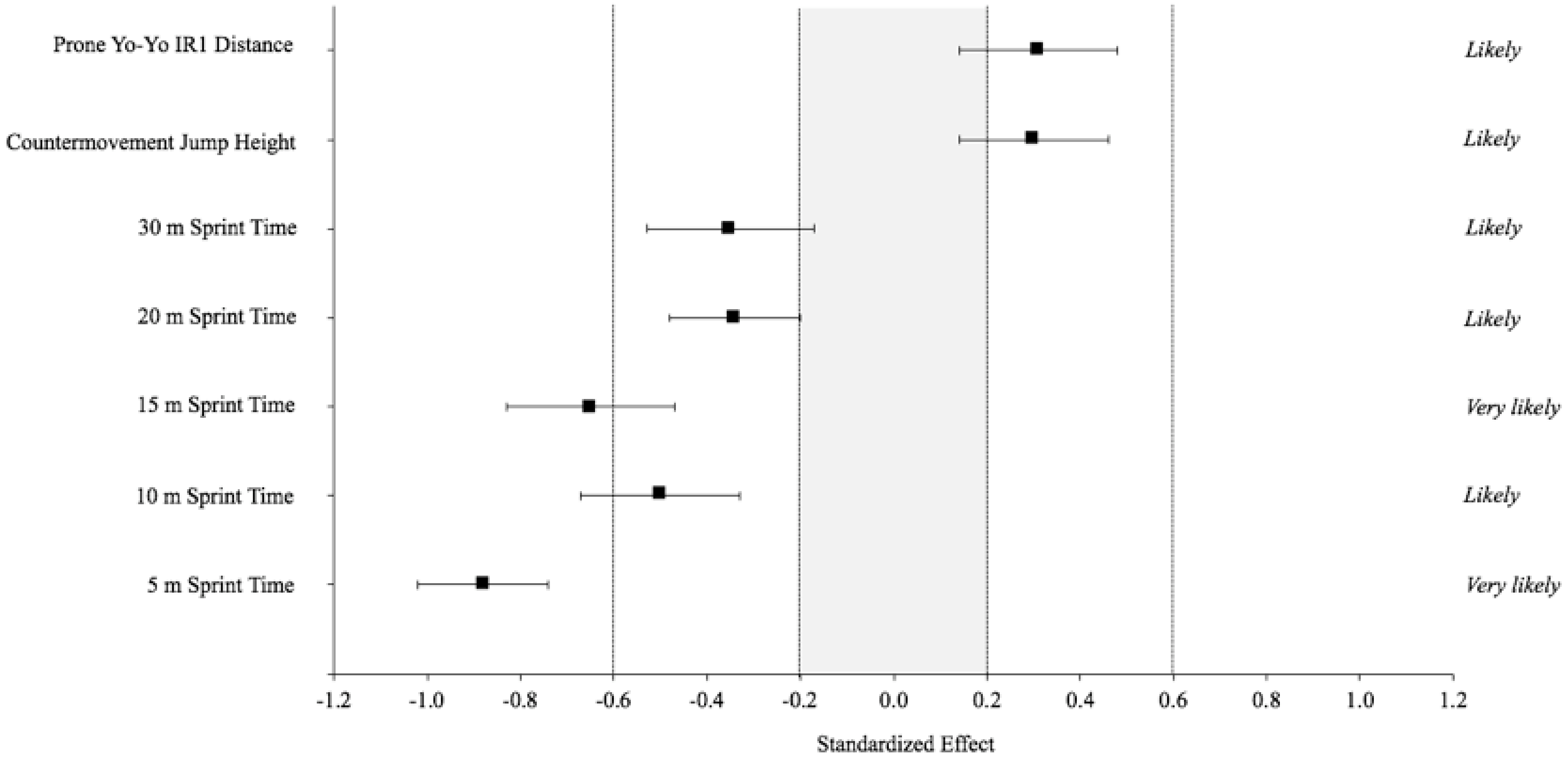

Figure 1. The standardized differences in performance of players during the trial with compared to without the coaches observing.

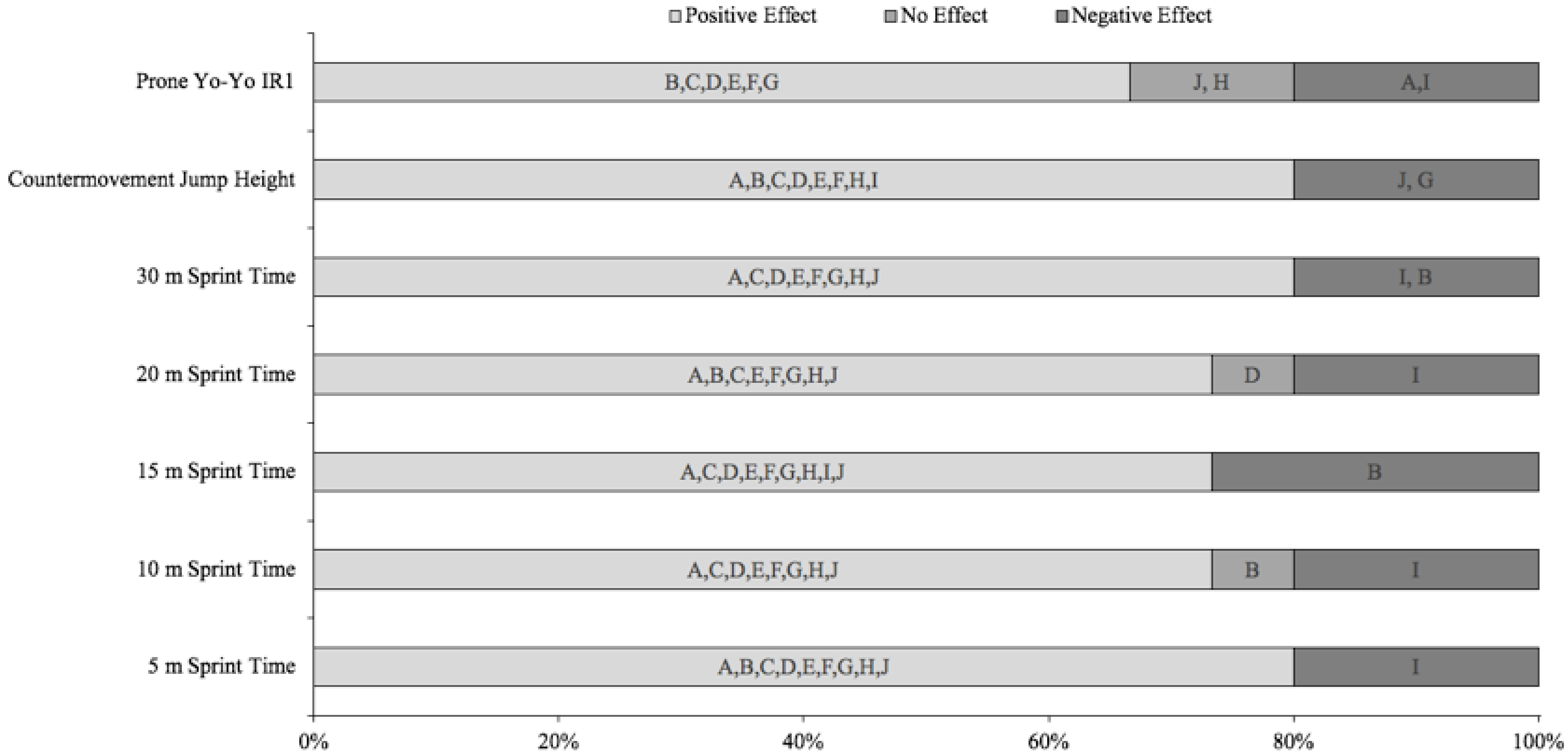

Figure 2. The percentage of participants that observed a positive effect, no effect or a negative effect during the trial with coaches observed compared with without.

Note: letter represent the participants and their respective qualitative responses to semi-structure interviews (not presented within this thesis).

Appendix 15. Synthesis

Systematic Review

Wide range of tests available for assessing the anthropometric and physical characteristics in rugby league.

General lack of standardisation for the tests used and the procedures across the literature

Some issues around the measurement properties of tests commonly used.

Much of the research is limited to small samples from single clubs

Study 1

A reliable battery of tests using a sample of 50 players across three trials.

Combining the typical error and smallest worthwhile change provided a require change

No habituation is required when using academy rugby league players.

Study 2

The tests included appear to differentiate between playing standards.

Almost all components of the battery possess discriminant validity

Normative data

Study 3

The addition of an up/down action improved the relationship between this test and the internal, external and perceptual responses to simulated match play.

Should be favoured over the tradition test when working with rugby players.

Study 4

The inclusion of up/down actions increased the internal, external (except distance), metabolic and perceptual responses

Some unexplained variance suggesting the measurement of sport-specific characteristics

Study 6

Including the up/down action within training improved the responses to SIT.

Reduced the sub-maximal acceleratory responses during the prone Yo-Yo IR1 post-intervention

Did not elicit notable reductions in wellbeing and neuromuscular function

Study 5

Large number of associations between anthropometric and physical characteristics.

The characteristics are influenced by contextual factors including league position, playing position, season phase and playing age.