High-intensity Interval Training in Team Sports:

Testing, Monitoring and Prescription

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ABSTRACT

Aerobic fitness and repeated high-intensity efforts have been shown to be a determinant in the performance of team sports, especially in the ability to finish a match, to cover a distance, to repeat and recover between sprints and explosive movements (e.g. accelerations, changes of direction; COD) and to reduce the deterioration in some technical skill. Due to this, coaches must appropriately develop these capacities to adequately prepare athletes for match-play demands. High-intensity interval training is considered an effective and time efficient means to optimise individual physiological adaptation. However, the best processes which examine these qualities (physical testing protocols), prescribe training and monitor the response of this training requires attention, particularly in team sport athletes that possess heterogenous physical attributes. Therefore, this thesis aimed to examine a valid and reliable approach to assess the training outcome as well as prescribe and monitor the training process in rugby league athletes.

Chapter III examined the reliability and usefulness of the 30-15 Intermittent Fitness Test (30-15_{IFT}) within rugby league. Fifty-five elite-junior rugby league players participated in the study. These included representative players from Under 16's (n=19, 15.6 ± 0.3 y, 78.1 kg ± 10.9 kg), Under 18's (n=21, 17.4 ± 0.5 y, 86.9 ± 11.2 kg) and Under 20's (n=15, 19.4 ± 0.5 y, 95.9 ± 8.7 kg) squads within a professional rugby league club. Players performed the 30-15_{IFT} twice within nine days of each other. Coefficients of variation (%CV) were 1.9% (95% CI, 1.6-2.4) for the combined test-retest of the 30-15_{IFT} and 0.6% (0.5-1.0) for HR_{peak}. As the typical error of measurement (TE) (0.36 $km{\cdot}h^{-1}$) was greater than the smallest worthwhile change (SWC) (0.20 $km{\cdot}h^{-1}$) value, the usefulness of the V_{IFT} was rated as 'marginal' (TE > SWC). The TE for HR_{peak} was

similar to the SWC, rating the usefulness of this variable as 'OK'. Despite the usefulness of the 30-15$_{IFT}$ being deemed 'marginal', a change as small as 0.50 km·h^{-1} (1 stage) in V$_{IFT}$ was considered substantial or 'real'. As a consequence, the 30-15$_{IFT}$ presents both a reliable and useful field test to assess intermittent fitness within rugby league players.

Chapter IV examined the construct validity of the 30-15$_{IFT}$ within rugby league. Sixty-Three Australian elite and junior-elite rugby league players (22.5 ± 4.5 y, 96.1. kg ± 9.5 kg, Σ7 skinfolds: 71.0 ± 18.7 mm) from a professional club participated in this study. Players were assessed for anthropometry (body mass, Σ7 skinfolds, lean mass index), prolonged high-intensity intermittent running (PHIR; measured by 30-15$_{IFT}$), predicted aerobic capacity (estimated from the multi-stage fitness test; $\dot{V}O_2max_{MSFT}$) and aerobic power (average aerobic speed), speed (40 m sprint), repeated sprint and change of direction (COD; 505 agility test). Validity of the 30-15$_{IFT}$ was established using Pearson's coefficient correlations. Forward stepwise regression model identified the fewest variables that could predict V$_{IFT}$ and change in 30-15$_{IFT}$ performance. Significant correlations between V$_{IFT}$ and Σ7 skinfolds, repeated sprint decrement, $\dot{V}O_2max_{MSFT}$ and average aerobic speed were observed. A total of 71.8% of the adjusted variance in 30-15$_{IFT}$ performance was explained using a 4 step best fit model ($\dot{V}O_2max_{MSFT}$, 61.4%; average aerobic speed, 4.7%; maximal velocity, 4.1%; lean mass index, 1.6%). These findings demonstrate that whilst the 30-15$_{IFT}$ is a valid measure of PHIR, it also simultaneously examines various physiological capacities that differ between sporting cohorts.

Chapter V determined differences in PHIR performance and running momentum (p_{IFT}) between competition levels and positional groups in rugby league. Elite Australian National Rugby League (NRL), sub-elite [state-based competition (SRL); national youth competition (NYC); local league (LL)] and junior-elite (U18; U16) rugby league players completed the 30-15$_{IFT}$ to quantify PHIR performance. Running momentum ($p_{IFT;}$ kg·m·s^{-1}) was calculated as the product of body mass and final running velocity ($V_{IFT;}$ m·s^{-1}). Effect sizes (ES ± CI) were used to examine between-group differences. 30-15$_{IFT}$ performance was *possibly* to *likely* higher in NRL players (19.5 ± 1.0 km·h^{-1}; mean ± SD) when compared to SRL (18.9 ± 1.0 km·h^{-1}; ES= 0.6 ± 0.5), NYC (18.9 ± 1.0 km·h^{-1}; ES = 0.6 ± 0.5) and U18 (18.6 ± 1.2 km·h^{-1}; ES = 0.8 ± 0.5) players. NRL players (537 ± 41 kg·m·s^{-1}) possessed *possibly* to *very likely* greater p_{IFT} than SRL (506 ± 50 kg·m·s^{-1}; ES = 0.7 ± 0.5), NYC (484 ± 50 kg·m·s^{-1}; ES = 1.2 ± 0.5), U18 (447 ± 37 kg·m·s^{-1}; ES = 2.3 ± 0.6), U16 (399 ± 50 kg·m·s^{-1}; ES = 3.0 ± 0.7) and LL players (466 ± 31 kg·m·s^{-1}; ES = 2.0 ± 0.7). Middle forwards attained a *likely* superior p_{IFT} (ES = 0.5−1.8) to all other positional groups. This study demonstrated that higher level rugby league players possess superior PHIR capacities compared with lower levels of competition, while highlighting that p_{IFT} can account for the disparities in body mass between groups.

Chapter VI compared relative and absolute speed and metabolic thresholds for quantifying match output in elite rugby league. Twenty-six professional players competing in the NRL were monitored with global positioning systems (GPS) across a rugby league season. Absolute speed [moderate-intensity running (MIR >3.6 m·s^{-1}); high intensity running (HIR > 5.2 m·s^{-1})] and metabolic (>20 W·kg^{-1}) thresholds were compared to individualised ventilatory [first (VT_{1IFT}), and second (VT_{2IFT})] thresholds estimated from the 30-15$_{IFT}$, as well as the metabolic threshold associated with VT$_{2IFT}$ (HP$_{metVT2}$), to examine difference in match-play demands. VT$_{2IFT}$ mean values represent a 146%, 138%, 167% and 144% increase in the HIR dose across adjustables, edge forwards, middle forwards and outside backs. Distance covered above VT$_{2IFT}$ was *almost certainly* greater (ES range = 0.79 – 1.03) than absolute thresholds across all positions. These findings demonstrate that using absolute HIR speed thresholds may underestimate the relative HIR load. *Chapter VII* evaluated the validity of the relative speed thresholds proposed in *chapter VI.* Eighteen professional male rugby league players (n= 18, 23.3 ± 3.4 y, 101.5 ± 8.3 kg) competing in the NRL competition, were monitored over a three-week pre-season training period (14.8 ± 0.8 field-based sessions) to examine the relationships between relative locomotor output and measures of internal load. This study observed moderate to large associations between these relative measures of external load and criterion measures of internal TL. This study concluded that V$_{IFT}$-derived thresholds are valid as a measure of quantifying training. Taken together, *Chapter VI and VII* suggest using relative thresholds allow for better prescription and monitoring of external training loads, whilst incorporating individual physical capacities.

Chapter VIII examined the acute metabolic, cardiorespiratory and neuromuscular effects of differently structured HIT and tactical training sessions, as well as changes following a pre-season training period. Thirty-one junior-elite Australian rugby league players completed four × 4 minute HIT exercises typical of team sport athletes with a 2 minute passive recovery in between exercises. Exercise intensity was prescribed relative to 30-15$_{IFT}$ performance conducted prior to each testing period, ranging from 85 – 105% V$_{IFT}$, with manipulations made to shuttle length, work: rest ratios, recovery modalities (active and passive) to alter the physiological response of each

HIT exercise. Blood lactate ($[La^-]_b$), counter-movement jumps (CMJ) and RPE were recorded following HIT exercises (within 60 s of completion), while time spent above 90% heart rate maximum (HR_{90}) was calculated. The order of HIT exercises where randomised over three protocols undertaken two days apart to assess the influence on exercise arrangement. Each protocol was re-tested following a six-week training period. Effect sizes (ES) quantified between-condition differences. Substantial increases in $[La^-]_b$ occurred following the second 4 min exercise bout (ES range = 0.94 – 1.18). No differences were witnessed following each protocol in $[La^-]_b$ or RPE, despite some substantial differences witnessed in HR_{90} between each protocol at the conclusion. The 4 min HIT exercise incorporating active recovery had the greatest effect on (ES range = 0.06 – 0.88). Following the training period, $[La^-]_b$ (protocol one; ES= 0.68 ± 0.31; ES ± CI) and HR_{90} (protocol one; ES = 0.75; ±0.37 and two: ES = 0.40; ±0.29) reposes were substantially lower. CMJ power outputs showed no substantial changes across any condition. These findings demonstrate that the arrangement of HIT exercises can influence the physiological responses of a training session. The accumulation of $[La^-]_b$ may be more sensitive to HIT incorporating active recoveries rather than HIT with greater mechanical (acceleration and deceleration) loads.

STUDENT DECLARATION

I, Tannath Scott, declare that the PhD thesis by publication entitled ‘High-intensity interval training in team sports: testing, monitoring and prescription’ is no more than 100,000 words in length, including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the aware of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

[redacted]

Tannath James Urquhart Scott

6^{th} June 2017

Date Submitted

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Well…. Wow! Over five years from starting this journey it ends (hopefully), and there were certainly times I didn't think I'd be writing this. For the very few of you who will take time out of your day to read this, these acknowledgements are directed right at you (whether you're mentioned or not!).

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LIST OF PUBLICATIONS ARISING FROM THIS THESIS

Peer-reviewed Articles

Scott, T. J, Delaney, J. A., Duthie, G. M., Sanctuary, C. E., Ballard, D. A., Hickmans, J. A and Dascombe, B. J. (2015). Reliability and usefulness of the 30-15 Intermittent Fitness Test in Rugby League. *Journal of Strength and Conditioning Research*, 29(7), 1985 – 1990.

Scott, T. J, Duthie, G. M., Delaney, J. A., Sanctuary, C. E., Ballard, D. A., Hickmans, J. A. and Dascombe, B. J. (2017). The validity and contributing physiological factors to 30-15 Intermittent Fitness Test performance in rugby league. *Journal of Strength and Conditioning Research*, 31(9), 2409 – 2416.

Scott, T. J., Dascombe, B. J., Delaney, J. A., Sanctuary, C. E., Scott, M. T. U., Hickmans J. A. and Duthie, G. M. (2017). Running momentum: a new method to quantify prolonged high-intensity intermittent running performance in collision sports. *Science and Medicine in Football*, 1(3), 244 – 250.

Scott, T. J., Thornton, H. R., Scott, M. T. U., Dascombe, B. J. and Duthie, G. M. (2018). Differences between relative and absolute speed and metabolic thresholds in rugby league. *International Journal of Sports Physiology and Performance,* 13(3), 298 – 304.

Conference Proceedings

Scott, T. J, Delaney, J. A., Duthie, G. M., Sanctuary, C. E., Ballard, D. A., Hickmans, J. A. and Dascombe, B. J. (2013). Predictors of intermittent running performance in rugby league. *19th Congress of the European College of Sport Science*, Amsterdam, The Netherlands.

Scott, T. J., Delaney, J. A., Duthie, G. M., Sanctuary, C. E., Ballard, D. A., Hickmans, J. A. and Dascombe, B. J. (2014). Effect of playing level on 30-15 Intermittent Fitness test performance in rugby league. *6th Exercise and Sport Science Australia Conference,* Adelaide. Australia. (*Appendix I*)

Scott, T. J. and McLaren, S. J. (2018). The validity of relative speed thresholds derived from the 30-15 Intermittent Fitness Test to quantify external training load in rugby league. *23rd Congress of the European College of Sport Science,* Dublin, Ireland.

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LIST OF ABBREVIATIONS

2kmTT	2000-m time trial
$30\text{-}15_{IFT}$	30-15 Intermittent Fitness Test
AAS	Average aerobic speed
ASR	anaerobic speed reserve
AU	arbitrary units
$b{\cdot}min^{-1}$	beats per minute
CI	confidence interval
cm	centimetre
CMJ	counter-movement jump
COD	change of direction
CV	coefficient of variation
ES	effect size
GPS	global positioning systems
h	hour
HIR	high-intensity running
HIR_{Th}	absolute high-intensity running threshold
HIT	High-intensity interval training
HP_{metTh}	absolute high power metabolic threshold
HP_{metVT2}	high power metabolic threshold associated with VT_{2IFT}
HR	heart rate
HR_{max}	maximal heart rate
HR_{peak}	peak heart rate
HR_{90}	heart rate > 90% max
HRV	heart rate variability
HRR	post-exercise heart-rate recovery
Hz	hertz
ICC	Interclass correlation coefficient
kg	kilogram
km	kilometre
$km{\cdot}h^{-1}$	kilometres per hour
LL	local level rugby league competition
LMI	Lean mass index
m	metre
min	minute

$m \cdot min^{-1}$	metres per minute
$m \cdot s^{-1}$	metres per second
$m \cdot s^{-2}$	metres per second/ per second
MAS	maximal aerobic speed
MIR	moderate-intensity running
MIR_{Th}	absolute moderate-intensity running threshold
MSFT	multi-stage fitness test
n	number
NRL	National Rugby League
NYC	National Youth Competition
PCr	phosphorylcreatine
PHIR	prolonged high-intensity intermittent running
p_{IFT}	Final running momentum during $30\text{-}15_{IFT}$
RPE	rating of perceived exertion
s	seconds
SD	standard deviation
sRPE	session-RPE
SRL	state-based rugby league competition
SWC	smallest worthwhile change
TE	typical error of measurement
TL	training load
$T@\dot{V}O_2max$	time above 90% of $\dot{V}O_2max$
UM-TT	Montreal Track Test
V_{IFT}	final velocity achieved during the 30-15 Intermittent Fitness Test
VT_1	first ventilatory threshold
VT_2	second ventilatory threshold
VT_{1IFT}	relative first ventilatory threshold from $30\text{-}15_{IFT}$
VT_{2IFT}	relative second ventilatory threshold from $30\text{-}15_{IFT}$
$\dot{V}O_2$	oxygen consumption
$\dot{V}O_2max$	maximal oxygen uptake
$v\dot{V}O_2max$	minimal running speed required to elicit maximal oxygen uptake
y	year
Yo-Yo IRT	Yo-Yo Intermittent Recovery Test
Yo-Yo IRT1	Yo-Yo Intermittent Recovery Test Level 1
Yo-Yo IRT2	Yo-Yo Intermittent Recovery Test Level 2

$[La^-]_b$	blood lactate
%	percentage
~	approximate
>	greater than
<	less than
∑	sum
Δ	change (delta)

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Chapter I

General Introduction

BACKGROUND

To prepare athletes for team sport competition requires a fundamental understanding of the processes and outcomes of the physical training undertaken. The outcomes of specific training include anatomical, physiological, and functional adaptations specific to the sport, while the process is characterised by the progressive overload of physical training (see Figure 1.1) (Impellizzeri, Rampinini, & Marcora, 2005; Viru & Viru, 2000). Indeed, whilst the prescription of external load (training process) may be manipulated with an aim to maximise physiological adaptation it is the internal load that drives this training outcome (e.g. fatigue and adaptation) (Impellizzeri et al., 2005; Viru & Viru, 2000).. Through physical testing (considered the assessment of the training outcome), appropriate prescription of training stimulus, and systematic monitoring of the dose-response relationship, individual physiological adaptations can be optimised (Buchheit & Laursen, 2013b; Reilly, Morris, & Whyte, 2009). Ultimately, training outcomes should be intended to improve the individual capacity for physical match performance. Owing to this, performance coaches must employ a physical curriculum within team sports that aims to improve individual physiological deficiencies, advance movement qualities while physically preparing athletes for the most demanding periods of competition. Concurrently, there is a need to develop individualised programs for large squads whilst maintaining core elements of team work, and minimising injury risk (Reilly et al., 2009). Importantly, all this is required to coincide with technical and technical skills sessions to optimise adaptations without causing overtraining or non-functional overreaching (Coutts, Reaburn, Piva, & Rowsell, 2007). Collectively, this creates an often time-poor environment, meaning training programming must utilise efficient methods and have a clear outline of objectives that are centralised across performance and coaching departments.

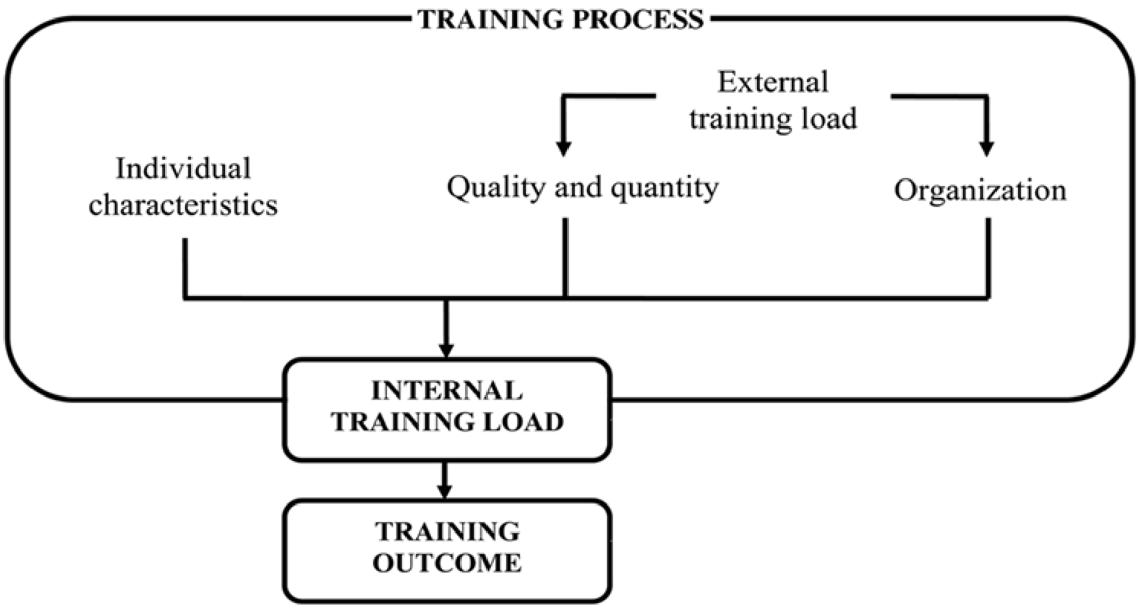

Figure 1.1: The conceptual model of the training process (Impellizzeri et al., 2005). The training outcome is the result of the internal training load. This internal training load is the product of: (a) Individual characteristics (training status and genetic makeup), and (b) The quality, quantity and organisation of the external training load.

Aerobic fitness has been shown to be a determinant in the performance of team sports, especially in the ability to finish a match (Kempton, Sirotic, & Coutts, 2015a; Mohr, Krustrup, & Bangsbo, 2003), cover greater distances (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b), to repeat and recover from high-intensities efforts (Bishop & Spencer, 2004; Dupont, McCall, Prieur, Millet, & Berthoin, 2010b), in executing technical proficiencies (Joseph, Woods, & Joyce, 2017) and to reduce the deterioration in some technical skills (Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009). In addition, it has been demonstrated that high-intensity efforts typically occur at decisive moments of match-play (Austin, Gabbett, & Jenkins, 2011) and may differentiate successful and non-successful teams (Gabbett & Gahan, 2015). Due to this, coaches must appropriately develop these aerobic and repeated high-intensity capacities to adequately prepare athletes for match-play demands.

High-intensity interval training (HIT) has become increasingly more common in physical training preparation for team sports, as it has been shown to be a time effective method that stresses the physiological capacities common to team sport match-play (Billat, 2001b; Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b). Typically, HIT incorporates either repeated short (<45 s) or longer (2-4 min) bouts of high-intensity exercise that are interspersed with set recovery periods (Buchheit & Laursen, 2013a). Given most team sports are largely acyclic in nature, the energy supply required for these physical efforts is derived collectively from both anaerobic and aerobic sources and requires high levels of neuromotor drive (Bangsbo, 2000b; Bangsbo, Iaia, & Krustrup, 2007; Bangsbo, Mohr, & Krustrup, 2006). As such, HIT protocols may not only aim to improve cardiorespiratory function (usually considered the primary aim) but focus on the metabolic and neuromuscular responses (Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b).

To achieve the desired physiological adaptations, physical conditioning programs must be specifically prescribed for individuals and consider current training state, training history and physiological demands of match-play. However, the dose-response relationship to this training stimulus must also be monitored. High-intensity interval training sessions have typically been prescribed using an individual's velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$) or an individual's maximal aerobic speed (MAS), traditionally measured through either a laboratory based treadmill test or estimated from field-based tests such as, the multi-stage fitness test (MSFT) (Ramsbottom, Brewer, & Williams, 1988) or the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IRT1) and/or Level 2 (Yo-Yo IRT2) (Bangsbo, 1994). However, the limitations concerning the ability to test these qualities [e.g. prolonged high-intensity intermittent running (PHIR)] and subsequently prescribe movement specific HIT protocols have previously been recognised (Buchheit, 2008b). For example, the MSFT may estimate $\dot{V}O_2max$, yet does not evaluate many qualities of intermittent performance (e.g. inter-effort recovery ability) (Haydar, Haddad, Ahmaidi, & Buchheit, 2011). In contrast the Yo-Yo IRT's examine these physiological determinants but do not provide a reference speed that is sensitive enough to guide the homogenous prescription of HIT (Buchheit, 2008b; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005). This is important as through the individualisation of HIT we may aim to maximise the training outcome (and potential physiological adaptation). For example, it has been demonstrated that only the time spent at high intensity (>90% of maximal HR) was related to changes in aerobic fitness in soccer players across a pre-season period (6-8 weeks) (Castagna, Impellizzeri, Chaouachi, & Manzi, 2013). As such, it appears vital that coaches prescribe and monitor workloads relative to each individual athlete in team sports.

RESEARCH PROBLEM

Aerobic fitness and repeated high-intensity efforts have been shown to be a determinant in the performance of team sports. Due to this, coaches must appropriately develop these capacities to adequately prepare athletes for match-play demands. High-intensity interval training is considered an effective and time efficient means to optimize individual physiological adaptation (Buchheit, 2011).The prescription of HIT requires the manipulation of up to nine variables (i.e. work: rest intervals, work intensity and duration, number of sets and repetitions and recovery between sets); any of which may alter the physiological response to training. However, establishing a reliable and valid testing protocol to establish a reference speed that may appropriately prescribe HIT velocities across large squads has limitations. The final velocity achieved during the 30-15 Intermittent Fitness Test (30-15_{IFT}; V_{IFT}) has been demonstrated to provide a reference speed delivering homogenous physiological responses during HIT (Buchheit, 2008b). However, the validity of the 30-15_{IFT} in team sports has been limited to primarily basketball, soccer, handball and ice hockey cohorts (Buchheit, 2008b; Buchheit, Lefebvre, Laursen, & Ahmaidi, 2011b; Covic, Jeleskovic, Alic, Rado, Kafedzic, Sporis, McMaster, & Milanovic, 2016). While V_{IFT} incorporates the ability of an individual to tolerate directional changes, it is theorised that individual COD ability may be affected by greater mass, due to the increased inertia and thus superior proportional impulse required to decelerate and re-accelerate (Frost, Cronin, & Newton, 2010). Due to this, it has been suggested that heavier team sport athletes (e.g. rugby league, rugby union, American football) would experience a greater mechanical and metabolic load throughout the 30-15_{IFT} compared to previously assessed cohorts (e.g. soccer or European handball players) (Darrall-Jones, Roe, Carney, Clayton, Phibbs, Read, Weakley, Till, & Jones, 2015). Further, it may be that in team sports where athletes possess heterogenous physical qualities, the prescribed training process may result in distorted physical responses. As such, the best process to examine these aerobic and intermittent fitness, prescribe training and monitor the response of this training requires attention.

RESEARCH OBJECTIVES

Despite the specificity of the $30\text{-}15_{IFT}$ test to rugby league, no literature has investigated the validity and reliability of this test among such a population. Due to the greater body mass of rugby league players, it's likely that greater mechanical and metabolic loads would be evoked throughout the $30\text{-}15_{IFT}$. Firstly, this series of studies aims to examine the reliability, usefulness and validity of this test among a primarily mesomorphic athletic population. Additionally, this research aimed to explore a new and novel method to both longitudinally track the PHIR capacity (assessed as $30\text{-}15_{IFT}$ performance) of athletes and monitor the relative physical output during match-play. Lastly, this body of research intended to provide a more complete understanding on the acute metabolic and neuromuscular effects of HIT prescribed from the $30\text{-}15_{IFT}$. Overall, these studies aimed to inform performance staff on practical and useful methods to test, prescribe and monitor the high-intensity running within large team sport squads.

RESEARCH PROGRESSION

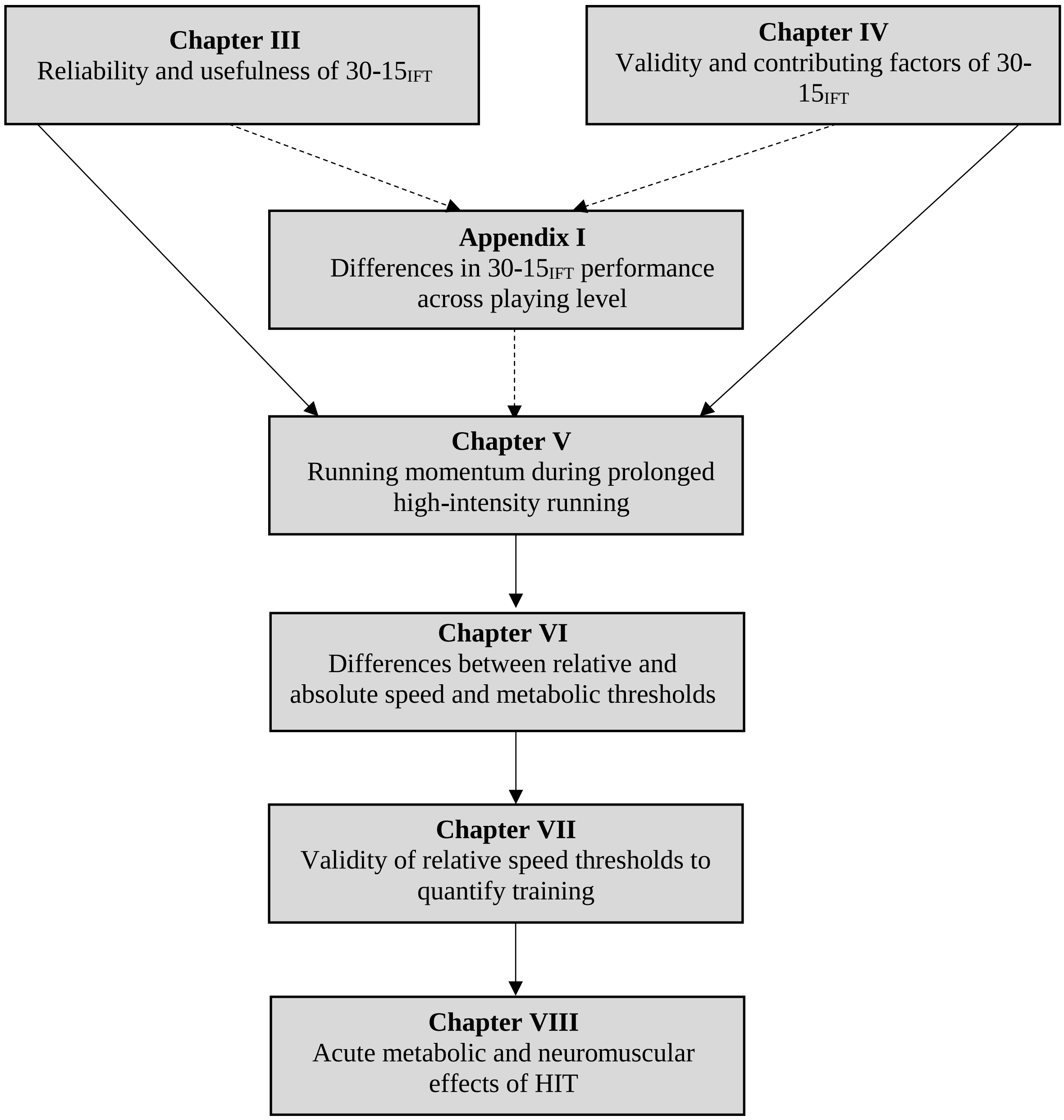

Figure 1.2: Outline of the research progress linking the major studies of this thesis.

PURPOSE OF THE STUDIES

The reliability and usefulness of the 30-15 Intermittent Fitness Test in Rugby League (Chapter III).

- To examine the reliability of the 30-15_{IFT} (V_{IFT} and HR_{peak}) within rugby league players;
- To assess the usefulness of the 30-15_{IFT} among this cohort through quantifying the smallest 'practical' changes in PHIR capacity.

The validity and contributing factors physiological factors to 30-15 Intermittent Fitness Test performance in rugby league (Chapter IV).

- Investigate and re-examine the validity of the 30-15_{IFT} among a typically mesomorphic population;
- Explore the contribution of physiological functions to V_{IFT} across positional groups in rugby league;
- Examine what changes in physiological capacities contributes to changes in V_{IFT} across a preparatory macrocycle.

Running momentum: a new method to quantify prolonged high-intensity intermittent running performance in collision sports (Chapter V).

- Determine if the calculation of PHIR 'final momentum' (p_{IFT}) may better distinguish between levels of competition and positional groups than traditional velocity based measures (V_{IFT});

- Investigate any differences in p_{IFT} and V_{IFT} between elite, sub-elite and junior-elite players.

Differences between relative and absolute speed and metabolic thresholds in team sports (Chapter VI).

- Identify the differences between relative and absolute speed and high metabolic power thresholds across rugby league match-play.

The validity of relative speed thresholds to quantify training in team sports (Chapter VII).

- Identify the construct validity of these newly proposed individual thresholds across rugby league training.

Acute metabolic and neuromuscular effects of high-intensity training in team sport athletes (Chapter VIII).

- Identify the metabolic and neuromuscular effects of different training exercises within a HIT session as prescribed from the $30\text{-}15_{IFT;}$
- Examine the influence by tactical/technical sessions undertaken immediately before the HIT protocol;
- Investigate individual metabolic and neuromuscular responses to the same HIT session following a training period (typical of pre-season).

LINKING THE RESEARCH MANUSCRIPTS

This research project aimed at providing a systematic process to practically test, prescribe and monitor the training process and outcomes of team sport athletes, specifically in rugby league. To achieve this outcome, the $30\text{-}15_{IFT}$ was employed to examine the PHIR capacity of these athletes and prescribe individualised HIT protocols. Due to a large somatic discrepancy between the current cohort and those athletes previously examined, *Chapter III* and *IV* aimed to determine the reliability and usefulness, as well as the validity and contributing physiological factors to $30\text{-}15_{IFT}$ performance in such a cohort. This research allows for additional investigation into applying this test to monitor and prescribe HIT. Subsequently, *Chapter V* investigated differences in $30\text{-}15_{IFT}$ performance across levels of competition, while introducing a new and novel method associated to tracking longitudinal PHIR performance. *Chapter VI* utilised previous research on the $30\text{-}15_{IFT}$ to design relative speed and metabolic thresholds to GPS-derived match-play loads. *Chapter VII* examined the validity of $30\text{-}15_{IFT}$ derived speed thresholds proposed in *Chapter VI*. The specificity of this relative running load aimed to provide greater insight into the volume of running performed at higher-intensities and consequently can be used by performance staff to more precisely monitor match-play and training sessions. Finally, *Chapter VIII* employed $30\text{-}15_{IFT}$-based HIT protocols to better understand the acute metabolic and neuromuscular fatigue associated with varying HIT strategies common in team sports. In addition, this chapter utilised speed thresholds developed in *Chapter IV* to further validate the use of these thresholds and relate the relative HIR load to these metabolic and neuromuscular outcomes.

Overall, this thesis aimed to investigate the implementation of the 30-15$_{IFT}$ to test PHIR, design and prescribe HIT protocols suitable for team sport athletes and monitor the dose-response relationship during training and match-play. As a result of these series of studies, new and novel methods to longitudinally asses PHIR capacity and examine relative HIR were developed. Both in their individual and collective capacities, these studies contribute to the current understanding of the physical development and preparation of team sport athletes for match-play.

LIMITATIONS AND ASSUMPTIONS

The following limitations apply to the studies reported in the current thesis.

Specificity of results

Whilst the studies implemented in this thesis were undertaken among a rugby league cohort, they relate to heterogenous collision-sport athletes (i.e. rugby league, rugby union, American football).

Interference in physiological responses

The heart rate measurements collected during the research can be influenced as a result of non-training factors, such as previous activity, psychological factors and nutrition, which may influence the results.

DELIMITATIONS

The following delimitations may apply to the present research:

Limited sample size

Due to the applied nature of the research, some studies may incorporate limited participant numbers. However, the sample size of each study is typical of previous research assessing similar performance outcomes in elite team sport.

Gender restrictions of the participants

The participants recruited across the research project were restricted to males to avoid any effect of gender on exercise performance.

Sample representation

The data contained within the entire research project are based on a specific sample of participants, and therefore may not be a true representation of similar populations.

Environmental conditions

Testing and training conditions across the studies contained in the thesis were commonly performed on a field in an open environment. Testing measures were performed at times the athletes typically trained to control for natural circadian rhythms and effect of dietary intake.

Dietary Intake

Whilst the team dietician provided nutritional and hydration strategies to all players as per club guidelines during individual studies, diet was never directly controlled.

Chapter II

Literature Review

INTRODUCTION

Background to High-Intensity Interval Training in Team Sports

High-Intensity interval training has been incorporated into training programs for the past 100 years (Billat, 2001a). Indeed, between the 1910s and 1930s, HIT was utilised by middle- to long- distance athletes in a similar manner to contemporary practices (Billat, 2001a). As the metabolic fundamentals of training became better understood, HIT programming incorporated shorter bouts of HIR, until Emil Zatopek popularised current HIT programming in the 1950s (Billat, 2001a). Over the past 20-40 years, the conception and understanding of the direct acute and longitudinal physiological responses and subsequent adaptations to these training methods has developed substantially, with HIT emerging as a primary method of conditioning team sport athletes (Billat, 2001a; Buchheit & Laursen, 2013b). While substantial evidence suggests that cycling-based HIT may improve specific physiological functions and physical performance (Billat, 2001a; Billat, 2001b; Laursen & Jenkins, 2002), the purpose of this literature review will focus on running-based HIT in a context specific to field-based team sport athletes.

High-intensity interval training is flexible and can be modified to stress specific physiological processes, with up to nine variables (including work intensity and duration, work: rest intervals, number of sets and repetitions and recovery between sets) being able to be manipulated to alter the imposed training stress (see Figure 2.1 below). These physiological functions typically include cardiopulmonary (i.e. $\dot{V}O_2max$; allowing reduced peripheral physiological disturbance and fatigue), metabolic (i.e. muscle lactate oxidation, H^+ ion buffering, Na^+/K^+ transport capacity, splitting of stored phosphagens and phosphocreatine resynthesis) (Buchheit, 2012; Buchheit & Laursen, 2013a) and neuromuscular (i.e. regulation of neural drive, muscle fibre recruitment and changes in force-generating capacity) related elements (Buchheit, 2012; Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b). It is appropriate to distinguish between these physiological processes as HIT methodologies are easily manipulated to stress these different qualities, with the aim to build toward inducing match specific training responses. Indeed, comparable HIT strategies may have similar cardiorespiratory responses yet markedly diverse neuromuscular and/or anaerobic contributions (Buchheit & Laursen, 2013a). As such, ruminating about the desired outcome of HIT sessions and considering the individual neuromuscular, metabolic and cardiorespiratory load are important when integrating into concurrent team sports training.

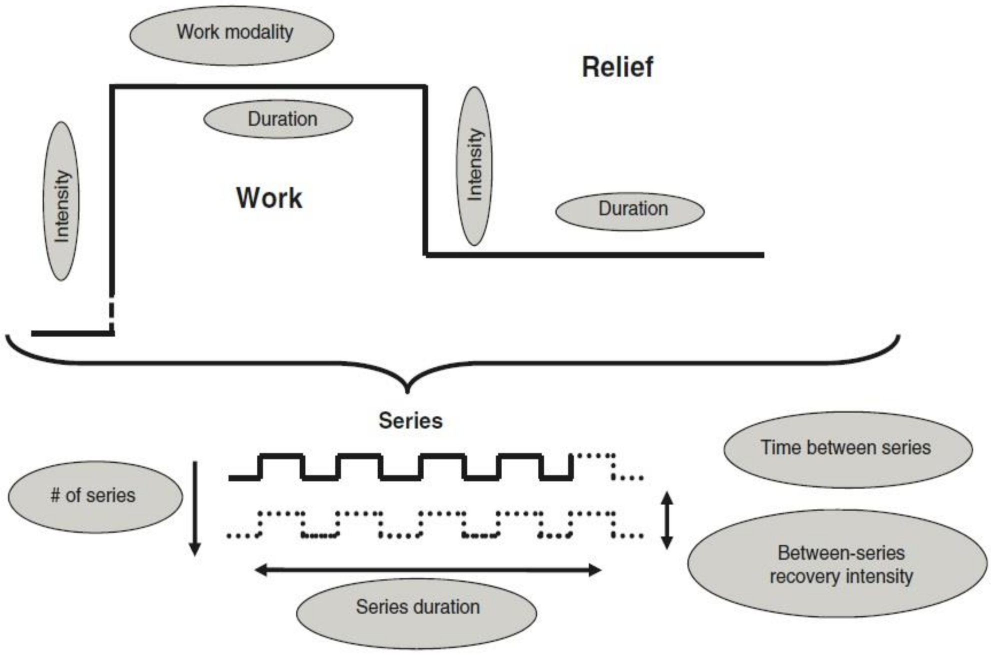

Figure 2.1: Variables that may be considered during high-intensity interval training. Taken from Buchheit and Laursen (2013b).

PHYSICAL TESTING

Background

The physical assessment of athletes in the field provides a valid and reliable means of examining various physiological capacities that are central to team sport performance (Bangsbo, 2000b). Pertinent to implementing any test in a team sport environment, is its validity (construct and ecological), reliability and usefulness (Bangsbo, 1994). Each test result should provide a repeatable outcome that delivers an increased understanding of physiological functioning and can be interpreted to guide the prescription of the training stimulus. Moreover, utilising a physical test that may deliver a reference workload to prescribe the training may increase the specificity of the feedback practitioners may receive (Buchheit, 2008b).

Within team sports, it is common to examine numerous physical capacities to gain a holistic physical understanding of individual athletes. These may incorporate assessments of aerobic and anaerobic capacities, repeated-speed, maximal speed, and acceleration qualities as well as change of direction and agility performance. In addition, laboratory based tests may be employed to further understand these physiological capacities, although they are often impractical with large squads. Field based tests offer far greater application and practicality to team sports (Reilly et al., 2009). As such, maximal running field tests are routinely undertaken to examine attributes and capacities to provide a basis for developing specific conditioning programs.

Continuous Running Tests

From the 1960s to 1980s an increase in research on the metabolic and energetic cost of walking, jogging, and running lead to the development of ecologically valid field tests to evaluate aerobic performance (Cooper, 1968; Jankowski, Ferguson, Langelier, Chaniotis, & Choquette, 1972; Shephard, 1969). These assessments of aerobic capacity were examined through continuous, indirect, and incremental running methods and become largely popularised in team sports due to their ability to test multiple athletes (Leger & Boucher, 1980; Leger, Mercier, Gadoury, & Lambert, 1988).

Montreal Track Test

The Montreal Track Test (UM-TT) is a continuous, indirect multi-stage running field test first developed as an alternative to a 12-minute maximal running test (Leger & Boucher, 1980). This test involves running continuously on a large field or track at a pace governed by a pre-recorded audio track, until the subject fails to maintain the incremental speed. The test was one of the first field used consistently in track and field and team sport athletes to predict $\dot{V}O_2max$ without having to conduct laboratory testing (Berthoin, Baquet, Rabita, Blondel, Lensel-Corbeil, & Gerbeaux, 1999; Leger & Boucher, 1980). The final velocity achieved during the test is considered a valid and reliable measure of maximal aerobic speed (Berthoin et al., 1999; Leger & Boucher, 1980). As such, the UM-TT final velocity has been utilised to prescribed individualised HIT stimulus, reducing the variability of the time to exhaustion during training between athletes. However, due to the continuous nature of the test, it does not incorporate the ability of the athletes to change direction or to recover between running efforts, limiting its use in team sport athletes.

Multi-stage Fitness Test

The MSFT (or 20-m Shuttle run test) was developed to overcome the limitations of the UM-TT. Whilst the UM-TT was both valid and reliable, it was limited by the field or track requirements (Leger & Lambert, 1982). The MSFT was developed to incorporate an athletes change of direction ability, with early research demonstrating that the MSFT provided a valid measure of aerobic fitness on a wide range of surfaces, which increased its popularity within team sports (Leger & Lambert, 1982). However, despite early studies indicating the MSFT to be both valid and reliable (Leger & Lambert, 1982), its ability to estimate $\dot{V}O_2max$ has recently been scrutinised. Lamb and Rogers (2007) suggested the MSFT was not reliable enough for the purpose of monitoring changes in $\dot{V}O_2max$ due to excessive non-random error, with only a moderate-strength relationship established between $\dot{V}O_2max$ (absolute and relative) and MSFT performance ($r = 0.43$ and $r = 0.54$, respectively) (Aziz, Chia, & Teh, 2005). Further, O'Gorman and colleagues (2000) reported no significant correlation between MSFT scores and laboratory-derived $\dot{V}O_2max$ for 7 international level rugby players ($r = 0.42$) or 15 competitive sports participants ($r = 0.41$), however the limited sample size used in this study makes drawing correlation conclusions difficult. Whilst these studies question the basis for the MSFT to measure and report changes in $\dot{V}O_2max$, it still may be an appropriate field based measure of running endurance. Indeed, the MSFT has been shown to be able to differentiate between competition levels (Gabbett, Jenkins, & Abernethy, 2011b; O'Connor, 1997) and age groups (Lovell, Towlson, Parkin, Portas, Vaeyens, & Cobley, 2015) across team sports. Additionally, it has been shown that the MSFT, combined with tests of speed and agility, may have a small but central association with the career progression of Australian football players (Pyne, Gardner, Sheehan, & Hopkins, 2005). Collectively, whilst this test may be a measure of running endurance, it may be that other field-based tests may not only estimate $\dot{V}O_2max$ more accurately than the MSFT, but also provide greater specificity to the intermittent running demands experienced in team sports.

Intermittent Running Tests

With an increased understanding of the physical demands of team sport match-play, field tests that examine physical capacities with greater transference to the demands of their sport are becoming more frequently employed. As such, it is important to examine both the aerobic and anaerobic capacities to match physical output of competition (Bangsbo, Iaia, & Krustrup, 2008), which has provoked a shift to assess the aerobic capacities through intermittent testing protocols (Bangsbo, 1994; Castagna, Abt, & D'Ottavio, 2005). The two most common physical tests to evaluate an athletes PHIR capacity are the Yo-Yo IRT and $30\text{-}15_{IFT}$ (Bangsbo et al., 2008; Buchheit, 2008b). Both these tests incorporate supra-maximal efforts (above $v\dot{V}O_2max$) and also incorporates an athlete’s ability to recover between incremental efforts. Combined with the COD, these tests provide an outcome of athlete’s inter-effort recovery ability, acceleration and deceleration ability, aerobic capacity, and anaerobic speed reserve (ASR). Whilst the direct constructs of these tests may vary slightly (Buchheit & Rabbani, 2014), both deliver a PHIR performance measure, which can be used to estimate $\dot{V}O_2max$.

Yo-Yo Intermittent Recovery Test

Originally, the Yo-Yo IRT1 and Yo-Yo IRT2 were developed as an extension of the MSFT to better reflect the mixed aerobic-anaerobic and intermittent profile typical of team sports. These test are commonly used to assess a players’ ability to perform intense intermittent exercise with brief periods of recovery, and both have been extensively reported upon in team sport athletes (Buchheit & Rabbani, 2014; Krustrup, Bradley, Christensen, Castagna, Jackman, Connolly, Randers, Mohr, & Bangsbo, 2015; Krustrup, Mohr, Amstrup, Rysgaard, Johansen, Steensberg, Pedersen, & Bangsbo, 2003; Krustrup, Mohr, Nybo, Jensen, Nielsen, & Bangsbo, 2006a). Briefly, this test involves 2 x 20 m shuttle runs at incremental speed that are interspersed with 10 s of active recovery. Endurance team sport athletes (i.e. soccer, Australian football) have typically completed the Yo-Yo IRT2, which increases speeds at a greater rate in order to exaggerate the intensity of the repeated high-intensity efforts. Indeed, while both the Yo-Yo IRT1 and IRT2 maximally stress the aerobic system, the latter evokes greater anaerobic metabolism which results in a shorter time to exhaustion (Krustrup et al., 2003; Krustrup et al., 2006a). The Yo-Yo IRT1 and IRT2 demonstrate both construct and ecological validity within team sport athletes and correlate well with other field and laboratory based physiological tests, (Krustrup et al., 2003; Krustrup et al., 2006a; Krustrup, Randers, Horton, Brito, & Rebelo, 2012; Povoas, Castagna, Soares, Silva, Lopes, & Krustrup, 2016). The reliability of the Yo-Yo IR1 and IR2 have been shown to be good (< 5.0% CV) (Krustrup et al., 2003) to moderate (5.1 – 10.0% CV) (Krustrup et al., 2006a; Thomas, Dawson, & Goodman, 2006).

Yo-Yo Intermittent Recovery Test performance has been shown to relate to match performance and distinguish between competition levels of many team sports [including soccer (Ingebrigtsen, Bendiksen, Randers, Castagna, Krustrup, & Holtermann, 2012; Krustrup et al., 2006a; Mohr et al., 2003; Rampinini, Bishop, Marcora, Ferrari Bravo, Sassi, & Impellizzeri, 2007a), Australian football (Pyne et al., 2005), rugby league (Atkins, 2006) and Gaelic football (Roe & Malone, 2016)]. For example, the Yo-Yo IRT2 test was shown to be a sensitive tool to differentiate between intermittent exercise performance of soccer players across different seasonal periods, competitive levels and playing positions (Ingebrigtsen et al., 2012; Krustrup et al., 2006a). However, a limitation of the Yo-Yo IRT is its inability to prescribe exercise based on individual performance during testing as it does not provide a sensitive reference speed for training purposes (Buchheit, 2008b). Indeed, despite previous equations developed to provide a sensitive HIT reference speed it appears problematic due to the nature of the test. (Kuipers, Verstappen, Keizer, Geurten, & van Kranenburg, 1985). For example, athletes can reach the same stage but complete a different number of shuttles resulting in difficulties optimising homogenous physiological responses during HIT.

30-15 Intermittent Fitness Test

The $30\text{-}15_{IFT}$ has been introduced as a practical alternative to the commonly used field tests mentioned above (Buchheit, 2010a; Buchheit, Laursen, Kuhnle, Ruch, Renaud, & Ahmaidi, 2009b; Haydar et al., 2011; Mosey, 2009). The $30\text{-}15_{IFT}$ is an intermittent, incremental shuttle-run test that is designed to elicit heart rate peak (HR_{peak}) and $\dot{V}O_2$peak, in addition to providing an overall measure of PHIR ability (Buchheit, Al Haddad, Millet, Lepretre, Newton, & Ahmaidi, 2009a). Briefly, the $30\text{-}15_{IFT}$ consists of 30-s shuttle runs interspersed with 15-s periods of passive recovery, with an initial running velocity (8 $km{\cdot}h^{-1}$) which is increased by 0.5 $km{\cdot}h^{-1}$ for every subsequent 45-s stage. Participants follow a pre-recorded beep as a pacing strategy over a 40-m shuttle. Similar to the Yo-Yo IRT and unlike continuous field based tests the $30\text{-}15_{IFT}$ evaluates individual players' inter-effort recovery, acceleration, deceleration and COD (Haydar et al., 2011) as well as evaluating concurrent aerobic and anaerobic metabolism. In addition, the 30-15_{IFT} has been perceived to be less "painful" than continuous field-based tests in 70% of team sport athletes examined (Buchheit, 2005a).

As the 30-15_{IFT} incorporates periods of recovery, V_{IFT} is much faster than $v\dot{V}O_2max$, whilst the inclusion of COD results in greater anaerobic metabolism than continuous incremental field tests. For example, the 30-15_{IFT} elicits a 40% increase in blood lactate concentration when compared to the UM-TT (Buchheit et al., 2009a), as well as higher peak minute ventilation and maximum carbon dioxide production due to the greater buffering of anaerobic metabolism by-products (Buchheit et al., 2009a). Buchheit et al. (2009a) observed that post exercise autonomic function was characterised by a decreased parasympathetic activity and a greater sympathetic predominance after the 30-15_{IFT} when compared to continuous running tests. This reduced parasympathetic modulation after 30-15_{IFT} agrees with previous data showing that anaerobic contribution and muscle power engagement influences post exercise parasympathetic reactivation (Buchheit, Laursen, & Ahmaidi, 2007). Importantly, this increased reliance on anaerobic metabolism toward the conclusion of the test may allow practitioners to further asses' individuals ASR. The consideration of individual ASR (the difference between maximal sprint speed and $v\dot{V}O_2max$) may further provide context to coaches to evaluate the capacity of their athletes to complete PHIR. The validity of this construct has been demonstrated in team sport athletes with the 30-15_{IFT} relating well to tests of anaerobic capacity (Scott, Hodson, Govus, & Dascombe, 2016a). As such, Buchheit (2010a) reported the contribution of the anaerobic capacity and neuromuscular qualities to the V_{IFT} reached is indirectly related to both the magnitude and the percentage of the ASR used during the final stages of the 30-$15_{IFT.}$

The $30\text{-}15_{IFT}$ has also been designed to easily integrate performance testing data into HIT prescription (Buchheit, 2008b), as this is a limitation of preceding field-based tests. For example, the MSFT may obtain a maximal running velocity, however certain physiological determinants of intermittent performance (e.g. inter-effort recovery ability and anaerobic speed reserve (ASR) are not evaluated (Haydar et al., 2011). In contrast the Yo-Yo IRT examine these physiological determinants and quantify PHIR performance, yet they do not deliver a sensitive reference speed that can be used for homogenous HIT prescription (Buchheit, 2008b; Krustrup et al., 2005). However, the $30\text{-}15_{IFT}$ provides a reference speed upon termination (V_{IFT}), that may be guide individual HIT programming (Buchheit, 2008b), overcoming the previous limitations discussed above. As such, prescribing HIT from V_{IFT} increases the homogeneity of training content across a team level (Buchheit, 2008b).

The validity and reliability of the $30\text{-}15_{IFT}$ has been demonstrated among numerous team sports [including basketball, soccer, handball and ice hockey; modified from running to ice skating) (Buchheit, 2008b; Buchheit et al., 2011b; Covic et al., 2016; Darrall-Jones et al., 2015). Previously, Buchheit (2008b) demonstrated significant relationships between V_{IFT} and CMJ, 10-m sprint time, $\dot{V}O_2$max, and heart rate recovery index scores in young athletes (randomly selected from two competitive basketball and handball teams), illustrating the construct validity of the $30\text{-}15_{IFT}$ for intermittent exercise. However, these assessments of validity and reliability have primarily occurred with ectomorphic populations, whereas heavier team sport athletes would experience greater mechanical and metabolic loads throughout the $30\text{-}15_{IFT}$ than these previously assessed cohorts (Darrall-Jones et al., 2015). While the $30\text{-}15_{IFT}$ incorporates the ability of an individual to tolerate these directional changes, it has been theorised that the ability to change direction may be affected by greater mass, due to the increased inertia and thus superior proportional impulse required to decelerate and re-accelerate (Frost et al., 2010). Limited research has explored the use of the 30-15$_{IFT}$ within a more mesomorphic athletic population. Interestingly, these limited findings reported that V_{IFT} remains relatively stable from U16 to senior rugby union players, despite a continued increase in body mass (Darrall-Jones et al., 2015), suggesting that the interaction between V_{IFT} and body mass may be of greater importance in sports where an increased body mass is ideal. As such, future investigations should explore the validity and reliability of the 30-15$_{IFT}$ among a more mesomorphic athletic population, typical of collision-based sports.

TRAINING PRESCRIPTION

The multifaceted nature of team sports creates considerable complexity when developing a training program and ensuring continued development in physiological capacities. A critical understanding of the specific determinants of performance and individual training status is a prerequisite in optimising the applied training stimulus. Team sport athletes are required to boast highly developed speed, agility, repeat-sprint ability, muscular strength and power profiles (Gabbett, 2005; Meir, 1994; Rampinini et al., 2007a; Sirotic, 2008), and as such a detailed understanding of training these specific areas is crucial (Reilly et al., 2009). Additionally, it is vital that team sport athletes also undertake considerable time to the tactical and technical elements involved in match play. Due to this complex combination of energetic, neural, skill and physical demands, coupled with specific time constraints, prescribing and periodising seasonal training may be difficult. Despite large advances in training prescription techniques for linear endurance and pure sprinting events, the development of team sport physical curriculum appears highly variable due to the complexity of physical requirements (i.e. speed, endurance and strength qualities through multiple planes of movement) (Reilly et al., 2009).

High-Intensity Interval Training

When planning and periodising training, the desired outcomes of individual running sessions and subsequent planned sessions are required to be identified to prepare team sport athletes for competition. This also allows greater integration between field-based running sessions with concurrent strength, speed, and agility sessions to improve resilience against injury and induce physiological adaptations in order to undertake tactical and technical sessions at higher intensities. Given that repeated high-intensity efforts are vital to team-sport match performance, the physical curriculum must aim to integrate and develop physiological adaptations across training periods that improve an individual's capacity to undertake PHIR. Targeted physiological capacities are generally best improved during the pre-season phase, when there is no regular match-play and travel to interfere. During this time, HIT sessions often progress their emphasis (from cardiopulmonary to greater neuromuscular focussed sessions (see Figure 2.2), with the aim to systematically development of the athlete's physiological capacities. Importantly, HIT may be easily manipulated to integrate with other training methods to maximise physiological adaptations across these periods of training.

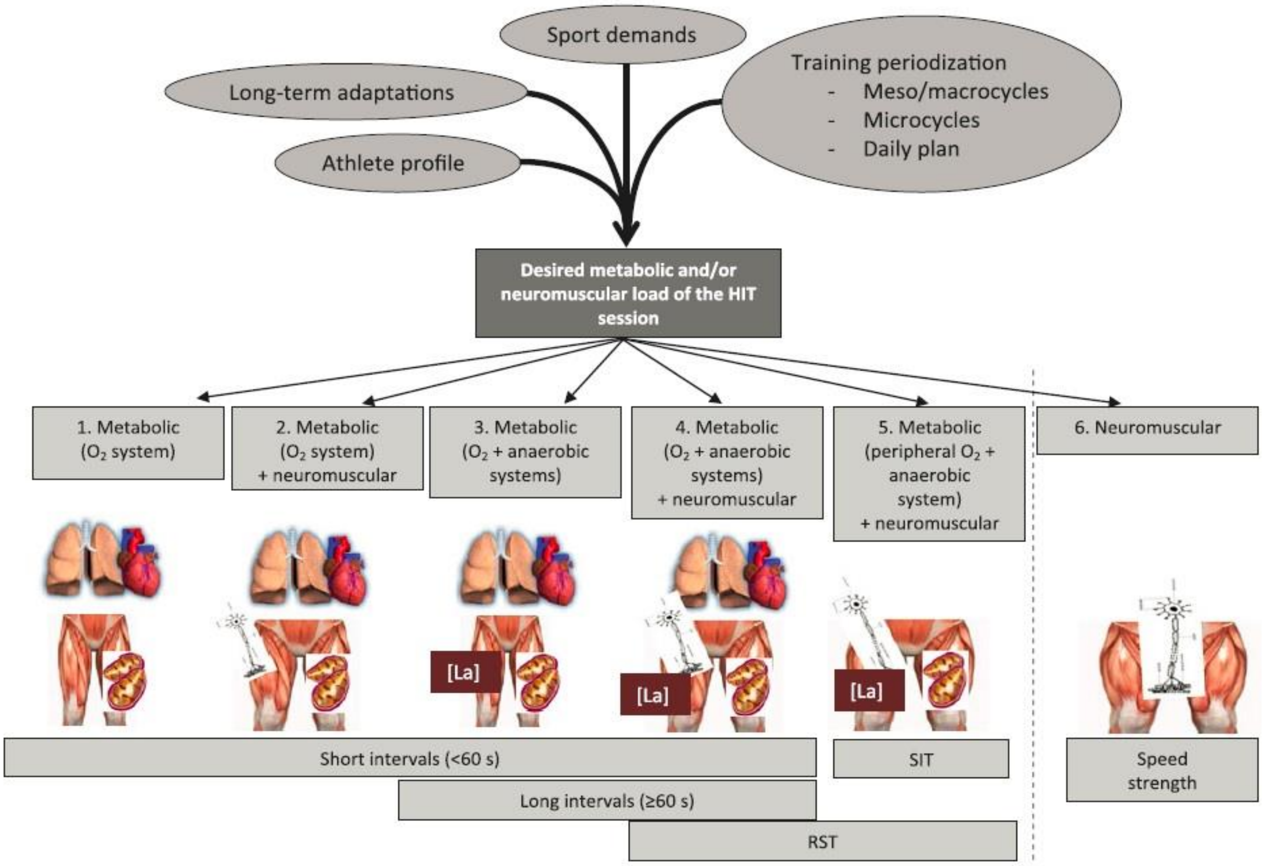

Figure 2.2: High-intensity interval training decision tree, considering individual drills based on the expected acute physiological strain responses. Taken from Buchheit and Laursen (2013b).

To increase the specificity of training in time-poor circumstances, skill-based conditioning (including small-sided games; SSG) has become increasing popular to develop the specific physical capabilities of match-play (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011; Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002). Through manipulating changes in technical rules (Dellal, Lago-Penas, Wong del, & Chamari, 2011), field size and player numbers (Rampinini, Impellizzeri, Castagna, Abt, Chamari, Sassi, & Marcora, 2007c) physiological loadings may be altered with similar longitudinal adaptations to traditional methods reported. However, the overall random nature of the such games, means that the overall load is problematic to standardised across individuals. For example, SSGs are highly variable when examining measures of internal (with reported blood lactate concentrations between 15−30% CV) and external (HIR 30–50% CV) loads (Hill-Haas, Coutts, Rowsell, & Dawson, 2008; Hill-Haas, Rowsell, Coutts, & Dawson, 2008). Moreover, such training methods may provide a ‘shotgun’ approach that encompasses both physical and technical training, it may be more difficult to systematically allow for the neuromuscular and metabolic systems to be overloaded. Consequently, while SSGs provide specific game-based training, their unpredictability presents difficulty when periodising the running load of athletes in team sports. As such, HIT may provide a useful method to complement this training throughout extended training blocks when there is greater need for specific physiological adaptation, due to its adaptability to target differing physiological capacities and qualities with specific outcomes (Hill-Haas et al., 2011; Hoff et al., 2002).

The manipulation of HIT can alter the physiological outcomes of training. Depending on the desired outcome, the prescription of training may incorporate longer (e.g. 1-2 min) efforts around $v\dot{V}O_2max$ to emphasise the cardiorespiratory (Faisal, Beavers, Robertson, & Hughson, 2009; Richard, Lonsdorfer-Wolf, Dufour, Doutreleau, Oswald-Mammosser, Billat, & Lonsdorfer, 2004), skeletal muscle oxygenation (Christmass, Dawson, & Arthur, 1999; Christmass, Dawson, Passeretto, & Arthur, 1999) and cardiac autonomic stress (Buchheit et al., 2007; Hammami, Kasmi, Yousfi, Bouamra, Tabka, & Bouhlel, 2016; Mourot, Bouhaddi, Tordi, Rouillon, & Regnard, 2004). Alternatively, shorter (e.g. 30 s) efforts with repeated changes of direction above $v\dot{V}O_2max$ increase the anaerobic glycolytic energy contribution and musculoskeletal/ neuromuscular stress (Buchheit, 2010b). However, all training stimulus will stress the metabolic, cardiopulmonary and neuromuscular systems to varying degrees. Importantly the periodising of HIT in team sports should recognise that each individual athlete has their own physiological profile to appreciate their acute response to the exercise.

For example, consider ‘athlete A’; they have a high aerobic capacity (and subsequent $v\dot{V}O_2max$) but low maximal sprint speed, reducing their ASR. ‘Athlete B’ has a contrary physiological profile, attaining a high maximal sprint speed but only moderate aerobic capacity. Both these athletes may undertake the same training stimulus but Athlete B will likely have a greater anaerobic contribution. Indeed, differences in ASR, $\dot{V}O_2max$, $v\dot{V}O_2max$ and maximal sprint speed between individual athletes are likely to change the aerobic and anaerobic contributions to an athlete performing PHIR, which may affect the accumulation of fatigue or performance. When prescribing HIT it is therefore important that this training elicits relatively homogenous physiological responses in order to reduce the variability of the associated fatigue. Conversely, consideration for the individual physiological profile should be undertaken when identifying appropriate methods to prescribe supramaximal HIT. The importance of ASR has been demonstrated, as higher maximal sprint speed proceeds high $v\dot{V}O_2max$ when athletes are performing HIR, given the metabolic power available from anaerobic sources (Bundle, Hoyt, & Weyand, 2003). Indeed, it has been established that ASR relates better to time to exhaustion during HIR (above $v\dot{V}O_2max$) than $\dot{V}O_2max$ (Bundle et al., 2003). As such, it is important that ASR and maximal sprint speed should be utilised, along with $v\dot{V}O_2max$ when individualising supramaximal HIT.

Heart Rate HIT Prescription

Through the utilisation of many physical tests (e.g. maximal $\dot{V}O_2max$ treadmill protocols, 30-15_{IFT}, MSFT), practitioners are provided with maximal heart rate (HR_{max}) values for each athlete which can then be used to prescribe HIT as a percentage of HR_{max} (Achten & Jeukendrup, 2003). The use of heart rate to prescribe training intensity is based on the linear relationship between HR and $\dot{V}O_2max$ during steady-state submaximal workloads (Arts & Kuipers, 1994; Åstrand & Rodahl, 1986; Hopkins, 1991; Robinson, Robinson, Hume, & Hopkins, 1991). As such, utilising HR zones to prescribe exercise intensity may be suited to prolonged and submaximal exercise bouts (Achten & Jeukendrup, 2003; Aubert, Seps, & Beckers, 2003). However, when prescribing HIT, any stimulus that is performed at or above $v\dot{V}O_2max$ suffers from a dissociation of this linear relationship, limiting its use in team sports (Laursen & Jenkins, 2002). Whilst other external factors such as environmental conditions, medication and hydration status may influence the heart rate response to HIT (Lambert, Mbambo, & St Clair Gibson, 1998). Hence, the use of heart rate to prescribe HIT is limited due to the lack of association during supramaximal exercise.

Rating of Perceived Exertion HIT Prescription

Rating of perceived exertion (RPE) that is typically employed to quantifying training intensity (Morgan, 1973; Robertson & Noble, 1997) and subsequent training loads (Foster, Florhaug, Franklin, Gottschall, Hrovatin, Parker, Doleshal, & Dodge, 2001). Rating of perceived exertion is thought to better reflect exercise intensity than isolated individual physiological variables as it integrates sensory information from peripheral muscles and joints, central cardiovascular and respiratory functions as well as the central nervous system (Borg, 1973). Further, RPE has been shown to correlate highly to internal measures of TL, such as heart rate and blood lactate (Coutts, Rampinini, Marcora, Castagna, & Impellizzeri, 2009; Noble, Borg, Jacobs, Ceci, & Kaiser, 1983) and has been proven to be valid for intermittent exercise (Foster et al., 2001; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). Whilst RPE has successfully been used to prescribe exercise intensity in runners (Dantas, Doria, Rossi, Rosa, Pietrangelo, Fano-Illic, & Nakamura, 2015), this method is seldom used in team sports for a variety of reasons (i.e. the heterogeneity of athletes, pacing strategies, and the mentality of conditioning sessions). Further, while this method may be valid in examining exercise intensity, its reliability has been reported to be poor (25–40% CV) (Scott, Black, Quinn, & Coutts, 2013; Wallace, Slattery, Impellizzeri, & Coutts, 2014). This is likely due to the additional psychological and biomechanical (Marcora, Staiano, & Manning, 2009) stressors imposed during exercise, which may be further influenced by external influences (Scott et al., 2013). While this may be appropriate when examining and monitoring the internal training load of an athlete longitudinally, these holistic psychophysical elements may reduce the homogeneity of the exercise intensity across a team.

Reference Speed-Based HIT Prescription

Typically, running intensities of interval-based training sessions have been set according to an individual's $v\dot{V}O_2max$ (Billat, 2001a; Billat, 2001b; Dupont, Akakpo, & Berthoin, 2004a). Whilst this review has outlined the limitations of continuous linear and shuttle-based field tests, they have provided the platform of prescribing exercise intensity from physical testing. Indeed, these methods originally proposed are seen as an objective way to individualise HIT (Billat, 2001a; Billat, 2001b; Dupont et al., 2004a) and have provided the fundamental basis from which interval training stimulus prescription has developed in intermittent team sports. Conceptually, in order to maximise physiological adaptations through HIT, intensities must be prescribed using a relative speed derived from a training outcome, accounting for athlete's individual physical characteristics. This method has been demonstrated to deliver a more homogenous physiological load than absolute distances (Buchheit, 2008b; Dupont, Defontaine, Bosquet, Blondel, Moalla, & Berthoin, 2010a). For example, Buchheit (2008b) reported that a more homogenous metabolic demand was associated with lower inter-individual differences using $30\text{-}15_{IFT}$ performance (V_{IFT}) as a reference speed for determining intermittent run distances that continuously determined running speeds. Through greater standardisation of the physiological load during HIT, performance staff are more precisely able to assess the prescribe training process against the completed training process. Therefore, reference-speed based HIT has become a popular conditioning tool to improve athlete physiological deficiencies allowing for a greater consideration of the separate cardiorespiratory/metabolic and neuromuscular/musculoskeletal strain/fatigue the athletes are exposed to across training.

MONITORING TRAINING LOADS

Athlete training monitoring and control systems are established on our understanding of the relationship between the training process and training outcome (see Figure 1.1 in *Chapter I*) (Impellizzeri et al., 2005). Although physiological tests (e.g. $30\text{-}15_{IFT}$, MSFT, Yo-Yo IRT) are commonly used to assess training outcomes, the training process is often quantified through training load (TL) (Coutts, Charmari, Rampinini, & Impellizzeri, 2008). This concept views the external TL as the main determinant of the internal TL response (however factors such as genetic make-up, training status and environment affect the individual response) (Booth & Thomasson, 1991). Through the repetition of physical training, the applied TL can be progressively overloaded, delivering a positive adaptation to the training outcome through the monitoring of external and internal TLs. Indeed, to integrate any conditioning training (including HIT) performance staff must monitor and review the dose-response relationship to the concurrent training program to provide the most effective facilitation of this stimulus.

Internal training load

It has been suggested TL is best quantified through exploring an individual's response to training stress (i.e. internal TL) (Impellizzeri et al., 2005). To assess internal TL, quantification of the duration and intensity of the training session are required to quantify the physiological stress imposed on by the training stimulus. While training duration is easily calculated, training intensity is a more difficult measure to quantify and is commonly quantified through measures of HR and RPE.

Heart Rate

As HR may be used to prescribe HIT, its use in monitoring the response of HIT appears fundamental. When aiming to optimise cardiovascular adaptions during HIT, it is believed that athletes should spend at least several minutes above 90% of $\dot{V}O_2max$ (T@$\dot{V}O_2max$) (Billat, 2001a; Buchheit & Laursen, 2013a; Midgley, McNaughton, & Wilkinson, 2006). Given measuring T@$\dot{V}O_2max$ is difficult and impractical to measure in the field with large squads, HR (specifically HR > $90\%_{max}$; HR_{90}) may present a more suitable alternative to assess the cardiopulmonary stress of HIT (Buchheit & Laursen, 2013b). However, the relationship between HR_{90} and T@$\dot{V}O_2max$ is highly dependent on the intensity and duration of work and rest periods (Buchheit & Laursen, 2013b), whilst is likely influenced by the limitations earlier described (e.g. disassociation between HR and exercise at supramaximal intensities (Impellizzeri et al., 2004). As such, alternate methods of applying HR data may provide better indications for fatigue sustained from HIT. Specifically, the ANS utilises both sympathetic and parasympathetic modulation (Robinson, Epstein, Beiser, & Braunwald, 1966) during and following exercise in order to maintain homeostasis (Pichot, Busso, Roche, Garet, Costes, Duverney, Lacour, & Barthelemy, 2002). While current findings are slightly ambiguous, it appears through monitoring indices of parasympathetic and sympathetic modulation (including HRV, HRR and changes in HR acceleration), the fatigue/adaptations related to HIT (and concurrent team sport training) sessions may be better understood. As such, by examining the ANS responsiveness to changes in training load, the body's ability to tolerate or adapt to HIT may be better assessed (Aubert et al., 2003; Borresen & Lambert, 2008), potentially indicating training status (Bellenger, Fuller, Thomson, Davison, Robertson, & Buckley, 2016).

Session-RPE

Proposed by Foster et al., (Foster et al., 2001; 1995) sRPE is an alternate method to quantify the internal TL experienced by athletes across an exercise bout. This simple strategy calculates internal TL by multiplying RPE (typically using Borg's CR10 scale) by the duration of the session (in minutes) to provide a calculated total TL that is representative of the entire session and is presented in arbitrary units (AU). Although originally designed for endurance athletes (Foster et al., 2001; Foster et al., 1995), this method has since been proven valid in quantifying session intensity in intermittent running (Foster et al., 2001; Impellizzeri et al., 2004; Scott et al., 2013).

As RPE can be used to prescribe HIT sessions, the monitoring of sRPE following these sessions may reflect whether athletes could holistically self-regulated the session as the coaches had planned. Importantly, the construct validity of sRPE to monitor TL in team sports has been witnessed across rugby league (Coutts, Reaburn, Murphy, Pine, & Impellizzeri, 2003; Gabbett & Domrow, 2007; Killen, Gabbett, & Jenkins, 2010; Lovell, Sirotic, Impellizzeri, & Coutts, 2013), rugby union (Cunniffe, Griffiths, Proctor, Davies, Baker, & Jones, 2010), soccer (Impellizzeri et al., 2004) and Australian football (Scott et al., 2013). Due to the simplicity of the sRPE method to quantify internal TL, there is a volume of research that quantifies the relationship between TLs and injury, illness, soreness [see review from Drew and Finch (2016)]. Indeed, when aiming to evaluate the acute and longitudinal physiological responses of HIT, it is imperative that a valid relationship exists between prescribed load and the internal response. This philosophy provides practitioners a starting point to assess the overload of their training program and evaluate the prescribed TL against the actual (or completed) TL. Importantly, RPE has been shown to be related to blood lactate during HIR (Dantas et al., 2015) and SSGs (Coutts et al., 2009), which may help to account anaerobic metabolism incurred through HIT, allowing greater consideration to the dose-response relationship.

External Training Load

The quantification of external TL has become more popular as more options have become available. Within team sports, prescribing training stimulus based on external TL (e.g. 6 x 100 m efforts) has always been an accepted tool, however an understanding of the intensity and force of these movements is highly desired. It is important to understand that TL is representative of the physiological responses induced by this external TL. Consequently, although potentially valid and reliable measures of external TL exist, this should not be done in isolation (Impellizzeri et al., 2005).

Global Positioning Systems (GPS)

The use of GPS technology to track player movement patterns (i.e. distance, HIR, repeated sprints, accelerations) has becoming increasingly popular amongst team sports. The ability to quantify external work completed is appealing as it provides valuable information that quantifies the demands of match-play to assist in prescribing training. However, despite its widespread use, the validity and reliability of these devices has been questioned, particularly during HIR (Coutts & Duffield, 2010; Gray, Jenkins, Andrews, Taaffe, & Glover, 2010; Scott, Scott, & Kelly, 2016b). These studies may have implications in quantifying the intensity of running undertaken during HIT as most the prescribed running is undertaken above these velocities (Laursen & Jenkins, 2002). However, the increased sampling rate (10-15 Hz) of more recent GPS units aim to overcome many limitations of earlier models allowing for greater use in accurately quantifying movement during HIT (Scott et al., 2016b), albeit with doubts over the ability to precisely quantify accelerations and decelerations (Buchheit, Al Haddad, Simpson, Palazzi, Bourdon, Di Salvo, & Mendez-Villanueva, 2014).

Despite a significant amount of research evaluating match and training demands of team sports, there appears to be little consensus on the speed zones (or thresholds) used to define work done. Given that many team sports incorporate athletes with substantially different physiological capacities, current methods to quantify varying intensities of running are limited across large heterogenous team sport squads. Moreover, as HIT is primarily undertaken at higher velocities, utilising relative speed thresholds may provide a greater reflection of the HIR undertaken by the individual having implications when assessing the integration of this work into training programs. Owing to this, there have been recent efforts to better understand physical demands of sports using relative thresholds (Abt & Lovell, 2009; Gabbett, 2015). For example, Gabbett (2015) analysed youth rugby league match-play using absolute and relative thresholds, relative to a players' individual peak velocity. This study reported that HIR distance, when expressed in relative thresholds, increased in slower players and decreased in faster players. Further, it has been revealed that distance covered at high-intensity is substantially underestimated when HIR is reported as a function of an individual's second ventilatory threshold (VT_2) (determined from expired gas-analysis during an incremental treadmill test) compared to absolute thresholds ($> 5.5\ m \cdot s^{-1}$) (Abt & Lovell, 2009). Similarly, Clarke et al., (2015) evaluated utilising VT_2 as a reference speed for HIR in rugby sevens, demonstrating absolute thresholds ($> 5.0\ m \cdot s^{-1}$) may over- or underestimate HIR by up to 14% during match-play. Whilst the proposed VT_2 speed threshold appears an appropriate physiological marker in examining HIR, its application in team sports may be limited due to the impracticality of regular laboratory testing for large squads (Abt & Lovell, 2009). Importantly, when evaluating the integration of HIT into training programs, it may be that using relative thresholds allows for more precise feedback of the HIR load. As such, practitioners may better understand the dose-response relationship allowing for greater precision in the planning of future training stimulus.

Collectively, GPS technology remains an important tool when integrating HIT into a training program. When examining changes in the internal response of athletes, it's important that performance have a representation of the external determinants undertaken. The quantification of external workloads based from individual physiological thresholds may further integrate the relationship between these two capacities. Through the understanding of each individuals' external load across all training, practitioners are able to adopt how to best implement HIT strategies into concurrent training to maximise physiological adaptations, whilst minimising injury occurrence. Moreover, these methods may give greater insights into the external factors of HIT prescription, understanding if the relative loads undertaken are comparable to the prescribed loadings.

CONCLUSIONS

When aiming to optimise the physical and physiological capacities of team sport athletes, it is imperative to recognise the relationship between the training outcome and training process. To achieve the desired physiological adaptations, training programs must incorporate specifically prescribed conditioning for individuals (taking into account current trained state, training history and physiological demands of match-play) whilst monitoring and reviewing the dose-response relationship to this training stimulus. Due to an increased understanding of the physical demands of team sport match-play, practitioners have shifted to utilise tests that examine physical capacities with greater transference to the demands of their sport. These physical tests may allow for a greater depiction of changes in the training outcome altered through physiological adaptations derived from specific training programs (considered training process). High-intensity interval training sessions have been typically prescribed to induce physiological adaptations specific to team sport athletes, typically as a percentage of an individual's $v\dot{V}O_2max$. However, the limitations concerning the ability to test these qualities (such as PHIR) and subsequently prescribe movement specific HIT protocols have recently been recognized (Buchheit, 2008b). When planning HIT sessions, the physiological capacities associated within team sports performance (i.e. individual players' inter-effort recovery, acceleration, deceleration and change of direction ability, aerobic capacity, ASR) must be considered before prescribing individualised HIT strategies. As such, the $30\text{-}15_{IFT}$ has recently been developed to overcome these limitations, allowing for the prescription of HIT strategies from the final speed attained during testing.

Given that both aerobic capacities and repeated high-intensity efforts are vital to team-sport match performance, the progressive overload of these HIT sessions must aim to integrate and develop the cardiopulmonary, neuromuscular/musculoskeletal and metabolic systems across training periods. However, appropriately periodising these processes within training can be problematic when attempting to evoke homogenous responses within a heterogenous athlete population. Utilising HR- and RPE- referenced HIT may be appealing as it is a direct evaluation of the internal TL experienced by the athlete, although both methods are limited by various physiological or psychophysical factors. Alternatively, utilising reference-speed based prescription, such as V_{IFT} provided from the $30\text{-}15_{IFT}$, results in a more homogenous physiological response across team sport athletes (Buchheit, 2008b).

The training dose-response relationship should be understood to maximise the likelihood of optimal athletic performance and reduce the negative effects of this relationship. Through considering how athletes tolerate the training process prescribed by the training outcome allows interventions to be applied within a periodised plan to deliver a positive training outcome. This relationship between the training process and training outcome provides the basis of training theory and the foundation from which training monitoring and control systems are developed (Coutts et al., 2008). However, owing to the multifaceted nature of the activity profile and energy supply in team sport match-play, the quantification of this concept requires measures across internal and external TL, combined with an understanding of the individual athlete. Training load monitoring systems should be intuitive, provide efficient data analysis and interpretation, and enable reporting of simple and valid feedback that promotes meaningful changes (Halson, 2014). Consequently, suitable monitoring of individual TLs may allow coaches to implement interventions to reduce injury risk and allow for greater optimisation of the training stimulus. Ultimately this feedback loop, quantifying the physiological capacities associated with the specific running demands in team sports, prescribing relevant training stimulus (including HIT) and the monitoring systems employed to examine the training process, must be aimed at improving the capacity for the athlete to perform during training and match-play. Through the utilisation and manipulation of HIT strategies, this training stimulus may provide an effective way to develop and optimise these physiological adaptations.

Chapter III

The reliability and usefulness of the 30-15 Intermittent Fitness Test in rugby league

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ABSTRACT

This study examined the reliability and usefulness of the 30-15 Intermittent Fitness Test (30-15$_{IFT}$) within rugby league. Fifty-five elite-junior rugby league players participated in the study. These included representative players from Under 16's (n=19, 15.6 ± 0.3 y, 78.1 kg ± 10.9 kg), Under 18's (n=21, 17.4 ± 0.5 y, 86.9 ± 11.2 kg) and Under 20's (n=15, 19.4 ± 0.5 y, 95.9 ± 8.7 kg) squads within a professional rugby league club. Players performed the 30-15$_{IFT}$ twice within nine days of each other. Maximal intermittent running velocity (V$_{IFT}$) and heart rate at exhaustion (HR$_{peak}$) were collected for both tests. Intra-class coefficients (ICC) for the 'Combined' and Under 20's were very large (r > 0.7); while the ICC for Under 16's and Under 18's were almost perfect (r > 0.9). Coefficients of variation (%CV) for V$_{IFT}$ were 1.9% (95% CI, 1.6-2.4) for the combined test-retest of the 30-15$_{IFT}$ and 0.6% (0.5-1.0) for HR$_{peak}$. As the typical error of measurement (TE) (0.36 km·h^{-1}) was greater than the smallest worthwhile change (SWC) (0.2 km·h^{-1}) value, the usefulness of the V$_{IFT}$ was rated as 'Marginal'. The TE for HR$_{peak}$ was similar to the SWC, rating the usefulness of this variable as 'OK'. Despite the usefulness of the 30-15$_{IFT}$ being deemed 'marginal', a change as small as 0.5 km·h^{-1} (1 stage) in V$_{IFT}$ was considered substantial or 'real'. As a consequence, the 30-15$_{IFT}$ presents both a reliable and useful field test to assess intermittent fitness within rugby league players.

Key Words: intermittent fitness, testing, maximum heart rate

INTRODUCTION

Rugby League is a physically demanding contact sport that involves frequent high-intensity movements (e.g. repeated high-speed running, sprint efforts and tackling) that are interspersed with periods of low intensity activity (e.g. standing, walking and jogging) (Austin & Kelly, 2013; Sirotic, Knowles, Catterick, & Coutts, 2011). Given this high-intensity intermittent nature, rugby league players must possess a well-trained high-intensity intermittent running ability in addition to a $\dot{V}O_2max$. Time motion analysis studies have demonstrated the intermittent nature of rugby league match-play finding that players playing in the Australian-based National Rugby League (NRL) competition spend between 10-17% of total match time undertaking high-intensity running movements that typically present in short bursts (Austin & Kelly, 2013; King, Jenkins, & Gabbett, 2009; Sirotic et al., 2011). Moreover, a recent study of positional match demands over a complete rugby league season found that high-intensity running (> 14 $km{\cdot}h^{-1}$) contributed to 14% and 17% of the distance covered by forwards and backs, respectively (Austin & Kelly, 2013). Further to these intermittent running demands, Sirotic et al. (2011) reported that players perform 30 or more sprints per match although these rarely exceed 50-m or 6-s. These sprint distances (mean value) ranged from 16.0-m for the fullback to 21.1-m for the other outside backs (centre and winger). Moreover, this study reported mean recovery periods between sprint bouts varied from 149-s to 284-s depending on positions. Collectively, these findings highlight that rugby league match play is highly intermittent, providing valuable information for testing and training.

In addition, past research has also demonstrated the high aerobic demands of rugby league match-play (Austin & Kelly, 2013; McLellan, Lovell, & Gass, 2011; Sirotic et al., 2011). Gabbett and colleagues (2011b) recently reported that estimated $\dot{V}O_2max$

could discriminate between elite (55.7 ± 2.9 $ml \cdot kg^{-1} \cdot min^{-1}$) and regional (53.2 ± 3.9 $ml \cdot kg^{-1} \cdot min^{-1}$) players. Importantly, this might reflect past observations that an individual's $\dot{V}O_2max$ may be a central factor in the recovery process between high-intensity efforts, as well as positively associated with prolonged high-intensity running exercise performance (Sirotic & Coutts, 2007). It has recently been demonstrated (Gabbett, Stein, Kemp, & Lorenzen, 2013) that professional rugby league players with a greater PHIR ability (classed as 'high fitness') covered significantly more total distance (6800 ± 1969 m and 4535 ± 1326 m, respectively), high-speed distance (> 18 $km \cdot h^{-1}$) (490 ± 141 m and 336 ±159 m, respectively) and played more time (70.1 ± 20.6 min and 47.5 ± 13.9 min, respectively) during a match than 'low fitness' individuals. Therefore, it is reasonable to suggest that improvements in $\dot{V}O_2max$ may significantly influence match-play performance in rugby league. Taken together, the collective sprint requirements and aerobic demands demonstrate the intermittent nature of rugby league match play.

As such, there is considerable value for rugby league conditioning and coaching staff to be able to assess $\dot{V}O_2peak$ and HIR ability to monitor the effectiveness of implemented conditioning regimes. Historically, $\dot{V}O_2peak$ in field-based sports has been routinely assessed using either the MSFT or the Yo-Yo IRT tests. Nonetheless, these protocols have limitations in the testing and prescription of these highlighted physiological capacities for intermittent team sport athletes (Buchheit, 2008b). For example, the MSFT may obtain a maximal running velocity, however certain physiological determinants of intermittent performance (e.g. inter-effort recovery ability and anaerobic reserve capacity) are not evaluated (Haydar et al., 2011). In contrast the Yo-Yo IRT examine these physiological determinants, providing a measurement of aerobic intermittent performance, yet they do not deliver a reference speed that can be used in the prescription of high-intensity intermittent runs (Buchheit, 2008b; Krustrup et al., 2005).

Recently, the $30\text{-}15_{IFT}$ has provided a practical alternative to the commonly used field tests mentioned above (Buchheit, 2010a; Buchheit et al., 2009b; Haydar et al., 2011; Mosey, 2009). The $30\text{-}15_{IFT}$ is an intermittent, incremental shuttle-run test that is designed to elicit HR_{peak} and $\dot{V}O_2peak$, in addition to providing an overall measure of intermittent fitness (Buchheit et al., 2009a). The validity and reliability of the $30\text{-}15_{IFT}$ has recently been demonstrated among basketball, handball and ice hockey cohorts (Buchheit, 2008b; Buchheit et al., 2011b). What makes this test appealing to practitioners is its validity in the individual prescription of high-intensity intermittent running, utilising the final running velocity (V_{IFT}) reached at the end of the $30\text{-}15_{IFT}$ (Buchheit, 2008b), overcoming the previous limitations of field-based tests discussed above. As such, prescribing training based on V_{IFT} appears to increase the homogeneity across the playing group and further standardising training content at a team level (Buchheit, 2008b). In addition the $30\text{-}15_{IFT}$ has been perceived to be less "painful" than continuous field-based tests in 70% of team sport athletes examined (Buchheit, 2005a).

Despite the specificity of this test to rugby league, no literature has investigated the validity and reliability of the $30\text{-}15_{IFT}$ in rugby league. Due to the greater body mass of rugby league players, it is likely that they would be required to produce a greater mechanical and metabolic load throughout the movement patterns involved in the $30\text{-}15_{IFT}$ (Buchheit et al., 2014; Haydar et al., 2011). Therefore, it is essential to re-investigate the reliability of this test among this population. The primary aim of the present study was to examine the reliability (including both V_{IFT} and HR_{peak}) of the 30-15_{IFT} within rugby league. A secondary purpose of the study was to assess the usefulness of the 30-15_{IFT} among this cohort.

METHODS

Experimental Approach to the Problem

In order to standardise testing, all tests were performed at the end of the pre-season period before the competitive season. To limit the circadian effect on performance, as well as to reduce the effect of external factors (such as heat), the testing procedures were either performed during the morning period (9.00 – 11.00 h) or evening period (16.00 – 18.00 h), when team practice usually took place. Testing sessions were repeated within nine days of each other. Two weeks prior to testing, subjects underwent a familiarisation session so they were aware of the running patterns and audio signals of the 30-15_{IFT}. Players were asked to refrain from undertaking any strenuous exercise in the 24-hour period prior to testing. Due to the specificity of the test and subsequent conditioning prescription, players tested in their training clothes and own football boots. The team dietician provided nutritional and hydration strategies to all players as per club guidelines. In order to ensure sufficient carbohydrate intake during this week, nutritional records were taken as was typical of club player monitoring policy. All sessions were performed in temperatures between 21-24°C. Reliability of the 30-15_{IFT} was examined using the intraclass correlation coefficient (ICC) as well as the typical error of measurement (TE), expressed as a coefficient of variation (%CV), similar to methods previously reported (Buchheit et al., 2011b).

Subjects

The subject pool (n=55) was comprised of players competing in the NSW Harold Matthews competition (Under 16's) (n=19, 15.6 ± 0.3 y, 176.6 ± 6.3 cm, 78.1 kg ± 10.9 kg, 62.2 ± 22.3 mm Σ7 skinfold), in the NSW S.G Ball competition (Under 18's) (n=21, 17.4 ± 0.5 y, 178.8 ± 5.5 cm, 86.9 ± 11.2 kg, 65.8 ± 20.8 mm) and in the National Youth Competition (Under 20's) (n=15, 19.4 ± 0.5 y, 95.9 ± 8.7 kg, 185.2 ± 3.3 cm, 67.8 ± 15.1 mm). Players completing in both the Harold Matthews and S. G Ball competition were involved in 5.9 ± 0.7 $hr·wk^{-1}$ of physical training, while players from the Nation Youth Competition completed 10.8 ± 2.1 $hr·wk^{-1}$. Players were familiarised with the testing protocols in the week prior to completing the test-retest trials. All players provided written informed consent prior to participation and were cleared of injury by the team's medical staff prior to completing the testing sessions. Parental or guardian consent was obtained before junior players were permitted to participate. The University of Newcastle Human Research Ethics committee approved the study methods (HREC no: H-2013-0283).

Procedures

The 30-15 Intermittent Fitness Test

The $30\text{-}15_{IFT}$ consists of 30-s shuttle runs interspersed with 15-s periods of passive recovery. The initial running velocity was set at 8 $km·h^{-1}$ for the first 30-s run and increased by 0.5 $km·h^{-1}$ for every subsequent 45-s stage. Players ran back and forth between two lines set 40-m apart at a pace governed by a pre-recorded beep. This pacing strategy allowed subjects to run at appropriate intervals and helped them adjust their running speed as they entered into 3-m zones at each end as well as the middle (20-m line) when a short beep sounds (Figure 3.1). During the 15-s recovery period, each player walked forward to the closest of the three lines (at the middle or at one end of the running area, depending on where the previous stage was completed), in preparation for the next stage. The test ended when a player could no longer maintain the imposed running speed or when they were unable to reach a 3-m zone around each line at the moment of the audio signal on three consecutive occasions. If players were unable to complete the stage, then their score was recorded as the stage that they last completed successfully, and the running velocity recorded as their maximal 30-15$_{IFT}$ running velocity (V_{IFT}) (Buchheit, 2005b; Buchheit, 2008b).

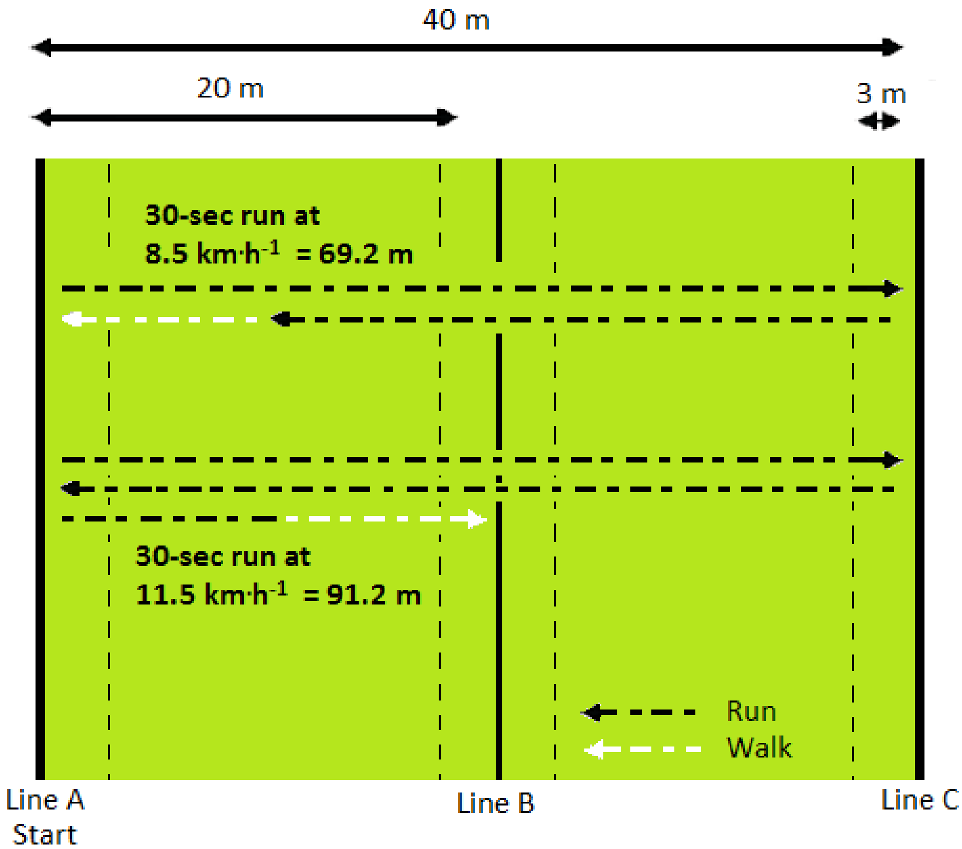

Figure 3.1: Schematic representation of the 30-15$_{IFT}$. Taken from Buchheit (2008b).

Heart Rate Measurement

Heart rate (HR) was recorded for a sub-sample (n=13) of (NYC) players using Polar T^2 system using R-R technology (Polar Electro Oy, Finland). Heart rate was continually recorded at 1 Hz throughout each 30-15_{IFT}. Peak HR (HR_{peak}) was recorded as the highest HR recorded during the final 30-s of the test.

Statistical Analysis

Data are presented as either mean ± SD or mean with 95% confidence intervals (95% CI) where specified. The distribution of each variable was examined using the Shapiro-Wilk normality test, and homogeneity of variance was verified with the Levene test. Paired sample t-tests were used to identify any significant differences between test-retest data. Change in mean between trials, ICC and TE, expressed as a CV, were calculated through an available online spreadsheet (Hopkins, 2015). As a criterion to declare the variable reliable, the CV was set at <5% (Hopkins, 2000). Hopkins (2004) has previously proposed that the smallest worthwhile change (SWC) is significant in the assessment of performance markers due to the noise associated with physical testing. As such, the SWC was calculated between trials for the final velocity reached at the completion of the test (equal to 0.2 multiplied by the between subject SD, based on Cohen's effect principle) (Hopkins, Schabort, & Hawley, 2001). In line with previous research, if the TE was higher than the SWC, the evaluation of test was 'marginal', if the TE was similar to the SWC, the evaluation was 'OK'; and if the TE was less than the SWC, an evaluation of 'good' was given to the test (Weir, 2005).

RESULTS

Data Collection

Due to difficulties such as injury and illness, several players (n=5) were unavailable for both testing days. These players were removed from the study with the final sample size (n=55) reflective of the number of players who completed both test-retest sessions. The HR data presented represents a sub-sample of 13 players from the NYC (U20's) Squad.

Reliability

The change in mean between trials is reported in Table 3.1, while TE, ICC and CV% are presented in Table 3.2. These tables report reliability values for each age group as well as playing position. The CV (%) values reported (1.9%) are less than what is typically required to be deemed reliable (<5%). This finding is consistent across all ages and all playing positional groups. An example of the individual heart rate responses during the repeated $30\text{-}15_{IFT}$ trials is illustrated in Figure 3.2 for one subject. Pairwise analysis revealed no significant differences between either V_{IFT} or HR_{peak} ($p < 0.05$) between the two trials.

Table 3.1: Mean (± SD) maximal intermittent running velocity (V_{IFT}) observed for the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$).

		V_{IFT} (km·h^{-1})		
$30\text{-}15_{IFT}$	**Players**	**Trial 1**	**Trial 2**	**Δ**
Squad				
NYC (U20's)	15	18.3 ± 0.8	18.4 ± 0.8	0.1 ± 0.5
SG Ball (U18's)	21	18.5 ± 1.2	18.6 ± 1.3	0.1 ± 0.5
Harold Matthews (U16's)	19	18.4 ± 1.0	18.6 ± 1.0	0.1 ± 0.5
Combined	55	18.4 ± 1.0	18.5 ± 1.1	0.1 ± 0.5
Heart Rate (b·min^{-1})				
NYC Sub-sample	13	194 ± 6	194 ± 6	-0.1 ± 1.8

Table 3.2: Measures of reliability for maximal intermittent running velocity (V_{IFT}) and peak heart rate (HR_{peak}) during the 30-15 Intermittent Fitness Test (30-15_{IFT}).

	Players	ICC	TE	(95% CI)	(95% CI)	CV (%)	(95% CI)	SWC	Test Rating
Squad									
NYC (U20's)	15	0.83	0.36	(0.26 - 0.57)	(0.56 - 0.94)	2	(1.4 - 3.1)	0.16	Marginal
SG Ball (U18's)	21	0.92	0.37	(0.29 - 0.54)	(0.81 - 0.97)	2.1	(1.6 - 3.0)	0.25	Marginal
Harold Matthews (U16's)	19	0.94	0.25	(0.19 - 0.38)	(0.86 - 0.98)	1.8	(1.3 - 2.7)	0.22	OK
Combined	55	0.89	0.36	(0.30 - 0.44)	(0.81 - 0.93)	1.9	(1.6 - 2.4)	0.21	Marginal
Heart Rate ($b \cdot min^{-1}$)									
NYC Sub-sample	13	0.96	1 $b \cdot min^{-1}$	(0.89 – 2.05)	(0.89 - 0.99)	0.6	(0.5 - 1.0)	1 $b \cdot min^{-1}$	OK

ICC = intraclass correlation coefficient; TE = typical error of measurement; CI = confidence intervals; CV = coefficient of variation; SWC = smallest worthwhile change

Test Usefulness

Typical error of measurement values for V_{IFT} was slightly greater than the calculated SWC, so it was classified as 'Marginal' for this variable (Table 3.2). Typical error of measurement values for HR_{peak} was similar to the calculated SWC, rating the usefulness of this variable as 'OK'.

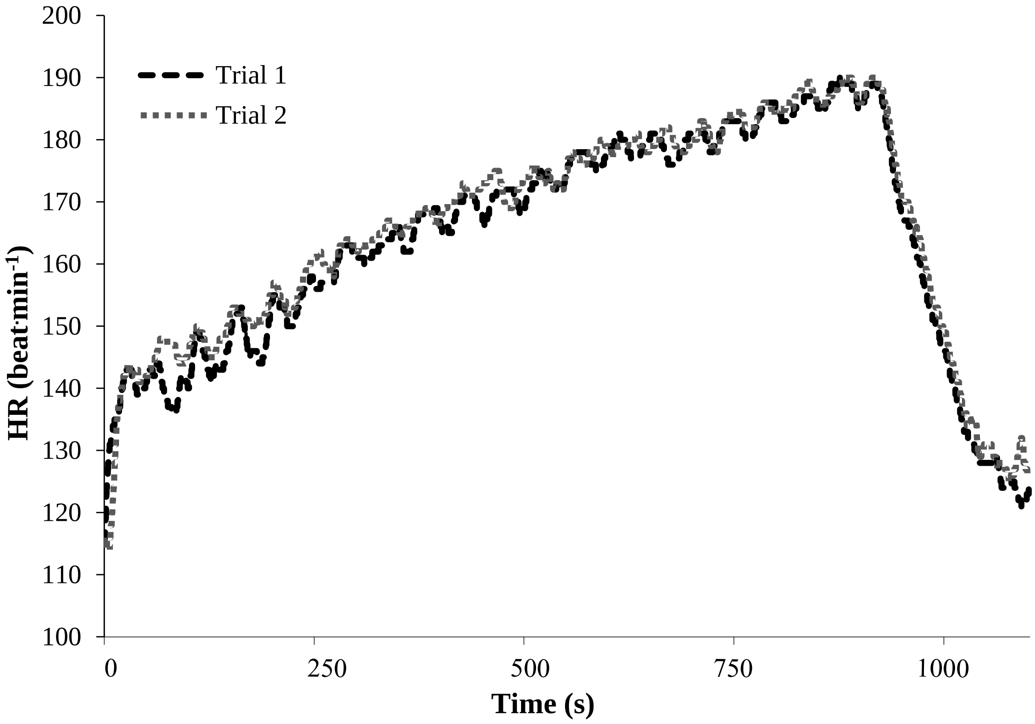

Figure 3.2: Heart rate (HR) response to the 30-15 Intermittent Fitness Test during two different trials [Trial 1 (black) and Trial 2 (grey)] in a representative subject.

DISCUSSION

The purpose of this study was to examine the reliability and usefulness of the $30\text{-}15_{IFT}$ within rugby league players. It was suggested that due to the separate morphological profiles, physiological and physical characteristics of rugby league players, the reliability of the $30\text{-}15_{IFT}$ may have differed when compared to previously examined cohorts (e.g. Ice hockey and European handball players). The main finding of the present study was that the $30\text{-}15_{IFT}$ showed good reliability across all playing groups within rugby league.

In agreement with previous research, our study showed that the reliability of the $30\text{-}15_{IFT}$ was *very good*, with a TE of 0.36 $km \cdot h^{-1}$ (CV 1.9%). These values are very similar to that reported previously by Buchhiet (2005b), who demonstrated the test-retest reliability of the $30\text{-}15_{IFT}$ to be very good (TE of 0.30 and CV value of 1.7%) among 20 regional-to-national level European handball players. Additionally, this result is comparable to findings previously reported in similar field based tests such as the Yo-Yo IRT1 [%CV for distance completed of 4.9-8.7% (Krustrup & Bangsbo, 2001; Thomas et al., 2006)] and Yo-Yo IRT2 [%CV values for distance completed of 7-13% (Bangsbo et al., 2008; Krustrup et al., 2006a; Thomas et al., 2006). Indeed, Thomas et al (2006) examined the reliability of the Yo-Yo IRT1 among 16 recreationally active subjects, and reported %CV values for distance completed of 8.7%, Yo-Yo IRT1 scores of 1.9% and a TE of 0.26. Further, the present study found the ICC of $30\text{-}15_{IFT}$ was very similar to that previously reported for the Yo-Yo IRT1 [ICC of 0.89 and 0.95 ($p < 0.01$), respectively].

Interestingly, a recent study examining the relationship between the performance of the Yo-Yo IRT1 and the $30\text{-}15_{IFT}$ were strongly correlated ($r = 0.75$) (Buchheit & Rabbani, 2014). The sensitivity across an 8-week training intervention between the two tests was also similar, despite these tests evaluating slightly different physiological capacities (Buchheit & Rabbani, 2014). Given that these tests are exhaustive, they incorporate complex physiological components (including cardiopulmonary, metabolic and neuromuscular related elements) that may vary and subsequently affect performance differently on a daily basis (Bangsbo et al., 2008), the reliability results appear particularly significant.

A further aim of the study was to evaluate the reliability of HR_{peak} assessed from the $30\text{-}15_{IFT}$. The reliability of HR measures (Table 3.2, Figure 3.2) supports previous research that has examined the reliability of HR_{peak} during a modified $30\text{-}15_{IFT}$ on ice, reporting a CV value of 0.7% (Buchheit et al., 2011b). Although the sample size used to investigate the reliability of HR_{peak} was small (Hopkins et al., 2001), previous research examining similar protocols with a comparable magnitude of subjects ($n = 12$), concluded that the good reliability likely limits the effect of the smaller sample size used (Buchheit et al., 2011b). Collectively, these results may be indicative of the specificity of this test to rugby league players in an ecologically valid environment. However, before this conclusion can be drawn, it is important to further investigate the validity of the $30\text{-}15_{IFT}$ and the contributing factors of this performance in rugby league.

A secondary purpose of the study was to assess the usefulness of the $30\text{-}15_{IFT}$ among a rugby league cohort. Despite the usefulness of the $30\text{-}15_{IFT}$ being deemed ‘marginal’, it must be noted that both the TE and SWC change were less than an increment of 1 stage. Therefore, from a practical point of view, a change as small as 0.5 $km \cdot h^{-1}$ (1 stage) in V_{IFT} could be considered substantial or 'real'. Although suggesting a SWC based on a whole squad's data could be considered a 'blanket approach', it might be deliberated as more appropriate for coaching and conditioning staff in a field setting. Indeed, it may be more accurate to calculate the inter-individual SWC [CV x 0.2, half of CV] (Hopkins, 2004). However, this would require a large amount of individual testing results to be deemed sensitive, as well as specific spreadsheets that make this method impractical for large squad's in team sports, particularly when there are high levels of homogeneity among the squad (Buchheit et al., 2011b). The results of this study support previous findings that a change of 1 stage is meaningful (Buchheit, 2005b; Buchheit, 2010a). Additionally, the usefulness of the HR_{peak} measures taken from the tests was rated as 'OK' (Table 3.2). It may then be concluded that HR_{peak} can be reliably measured using the $30\text{-}15_{IFT}$. However, due to the relationship between field-based $\dot{V}O_2max$ tests and HR_{peak}, supplementary examination into the validity of this measurement against a gold standard $\dot{V}O_2max$ protocol is justified amongst this present population group.

The outcome of the present study suggests the $30\text{-}15_{IFT}$ is a reliable test among a rugby league cohort. Rugby league players are typically mesomorphically built and are therefore physically different to previously examined players (e.g. European Handball). Moreover, the present study has provided evidence to coaching staff within similar team sports (e.g. rugby union) on what may be considered a 'real' change as well as establishing the usefulness of this test within rugby league. Although this study provides an assessment on the reliability of this test, further studies may focus on the validity and contributing factors of $30\text{-}15_{IFT}$ performance in order to establish further relationships between $30\text{-}15_{IFT}$, rugby league and its specificity to training regimes. Research may aim at more acutely examining the results of this data across positional groups as well as playing level. It may be reasonable to suggest that due to the morphological differences between forwards and backs, the current test may be able to distinguish playing groups. Indeed, recent evidence has suggested various anthropometric measurements and $\dot{V}O_2max$ can differentiate between levels of competition (Gabbett et al., 2011b). Therefore, future studies may focus on examining the influence of playing levels on 30-15_{IFT}, given the contribution of these former characteristics to 30-15_{IFT} performance.

LIMITATIONS

A limitation of the current manuscript was the absence of grass length and ground hardness from the test-retest analysis. Whilst this is unlikely to make a large difference, given the test was performed with nine days of each other on the same ground, it may be noted when interpreting the results.

PRACTICAL APPLICATIONS

The 30-15_{IFT} is a reliable and useful test to concurrently evaluate PHIR ability in rugby league players. From our results, it is reasonable to suggest the 30-15_{IFT} is reproducible and specific to rugby league players. The test is inexpensive, can simultaneously accommodate testing around 20 players comfortably, can be completed within 30 minutes, and requires little equipment and resources. The strong practicality of this test is that it can be accurately used for prescribing intermittent shuttle running compared to other similar field tests (Buchheit, 2008b). It is suggested that the 30-15_{IFT} is appropriate to monitor the intermittent fitness specific to rugby league players, and other team sports (e.g. rugby union, Australian football). Based on the TE and SWC values presented in this study, a change of 1 stage (0.5 $km \cdot h^{-1}$) can be interpreted as a ‘real’ change in performance. Due to the nature of the testing environment, it is suggested that the interpretation of data must take into account of weather and ground conditions.

Chapter IV

The validity and contributing physiological factors to 30-15 Intermittent Fitness Test performance in rugby league

This chapter is based on the peer-reviewed paper ***accepted and published*** in the Journal of Strength and Conditioning Research:

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ABSTRACT

This study examined the validity of the 30-15$_{IFT}$ within rugby league. Sixty-Three Australian elite and junior-elite rugby league players (22.5 ± 4.5 y, 96.1. kg ± 9.5 kg, Σ7 skinfolds: 71.0 ± 18.7 mm) from a professional club participated in this study. Players were assessed for anthropometry (body mass, Σ7 skinfolds, lean mass index), prolonged high-intensity intermittent running (PHIR; measured by 30-15$_{IFT}$), predicted aerobic capacity ($\dot{V}O_2max_{MSFT}$) and power (average aerobic speed; AAS), speed (40 m sprint), repeated sprint and change of direction (COD; 505 agility test) ability prior to and following an 11-week pre-season training period. Validity of the 30-15$_{IFT}$ was established using Pearson's coefficient correlations. Forward stepwise regression model identified the fewest variables that could explain V_{IFT} and changes within 30-15$_{IFT}$ performance. Significant correlations between V_{IFT} and Σ7 skinfolds, repeated sprint decrement, $\dot{V}O_2max_{MSFT}$ and average aerobic speed were observed. A total of 71.8% of the adjusted variance in 30-15$_{IFT}$ performance was explained using a 4 step best fit model ($\dot{V}O_2max_{MSFT}$, 61.4%; average aerobic speed, 4.7%; maximal velocity, 4.1%; lean mass index, 1.6%). Across the training period, 25% of the variance was accounted by Δ $\dot{V}O_2max_{MSFT}$ (R^2 = 0.25). These relationships suggest the 30-15$_{IFT}$ is a valid test of PHIR within rugby league. Poor correlations were observed with measures of acceleration, speed and COD. These findings demonstrate that whilst the 30-15$_{IFT}$ is a valid measure of PHIR, it also simultaneously examines various physiological capacities that differ between sporting cohorts.

Key Words: high-intensity interval training, testing, team sports

INTRODUCTION

In rugby league, players are often required to repeat high-intensity efforts match play. These efforts include repeated sprints, PHIR, jumping, tackling and/or collisions (Bangsbo, 2000a; Johnston, Gabbett, & Jenkins, 2014; Twist, Highton, Waldron, Edwards, Austin, & Gabbett, 2014), typically which occur at decisive efforts during match-play (Austin et al., 2011). Subsequently, the ability to repeat high-intensity efforts is a desirable physiological attribute. High-intensity interval training is commonly used as an effective means to improve the physiological qualities (including cardiorespiratory, metabolic and neuromuscular related elements) associated with high-intensity efforts (Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b). High-intensity interval training sessions have been typically prescribed using an individual's $\dot{V}O_2max$ or MAS, traditionally measured through either a laboratory based treadmill test or estimated from field-based tests such as, the MSFT (Ramsbottom et al., 1988) or the Yo-Yo IRT (Bangsbo, 1994). Interestingly, the limitations concerning the ability to test these qualities (such as PHIR) and subsequently prescribe movement specific HIT protocols have recently been recognized (Buchheit, 2008b). For example, the MSFT may obtain an estimated $\dot{V}O_2max$, yet does not evaluate many qualities of intermittent performance (e.g. inter-effort recovery ability) (Haydar et al., 2011). In contrast the Yo-Yo IRT1 and Yo-Yo IRT2 examine these physiological determinants without delivering a reference speed that can be used in the prescription of HIT (Buchheit, 2008b; Krustrup et al., 2005).

The $30\text{-}15_{IFT}$ is a graded intermittent shuttle based field test that is both valid and reliable in the individual assessment of PHIR ability (as described in *Chapter III*) (Buchheit, 2008b; Haydar et al., 2011; Scott, Delaney, Duthie, Sanctuary, Ballard, Hickmans, & Dascombe, 2015). The 30-15$_{IFT}$ incorporates many physiological capacities associated within team sports performance; including, individual players' inter-effort recovery, acceleration, deceleration and COD ability, aerobic capacity, PHIR ability (Buchheit, 2008b; Haydar et al., 2011). In addition, V_{IFT} has been demonstrated to provide lower inter-individual differences in the prescription of HIT than previous methods (Buchheit, 2008b). As a result, when compared to prescribing HIT based off $v\dot{V}O_2max$, the use of V_{IFT} has been shown to elicit greater homogenous cardiorespiratory responses during HIT (Billat & Koralsztein, 1996; Buchheit, 2008b). Whist this has great application in the prescription of HIT within team sports, it is vital that practitioners understand how these separate physiological capacities are associated to individual V_{IFT} performance. Therefore, it is important to determine and understand the link between traditional physiological factors and performance in the 30-15$_{IFT}$.

The shuttle-based, intermittent nature of the 30-15$_{IFT}$, appears specific to the movement patterns of rugby league (Austin et al., 2011; Waldron, Twist, Highton, Worsfold, & Daniels, 2011). Whilst the 30-15$_{IFT}$ has been shown to be valid as a test of PHIR ability, this has been primarily conducted in basketball, soccer, handball and ice hockey (Buchheit, 2008b; Buchheit et al., 2011b). Compared to straight line running, the 180 degree COD required for shuttle running typical of HIT training may elicit higher HR, RPE and blood lactate due to greater anaerobic energy requirement (Buchheit, Bishop, Haydar, Nakamura, & Ahmaidi, 2010; Buchheit, Millet, Parisy, Pourchez, Laursen, & Ahmaidi, 2008). While the 30-15$_{IFT}$ incorporates the ability of an individual to tolerate these directional changes, it is theorised that the ability to change direction may be affected by greater mass, due to the increased inertia and thus superior proportional impulse required to decelerate and re-accelerate (Frost et al., 2010). Due to this, it has been suggested that heavier team sport athletes would experience a greater mechanical and metabolic load throughout the $30\text{-}15_{IFT}$ compared to previously assessed cohorts (e.g. soccer or European handball players) (Darrall-Jones et al., 2015). Therefore, it is important that the validity of the $30\text{-}15_{IFT}$ is re-examined within this specific mesomorphic sporting demographic.

The purpose of this study was to: 1) investigate and re-examine the validity of the $30\text{-}15_{IFT}$ among a typically mesomorphic population that may exhibit altered responses during PHIR; 2) explore the contribution of physiological functions to V_{IFT} across positional groups in rugby league, and; 3) explore and understand what contributes to changes in V_{IFT} across a rugby league pre-season.

METHODS

Experimental Approach to the Problem

In order to assess the validity of the $30\text{-}15_{IFT}$, as well as the contributing factors to V_{IFT}, a battery of field and laboratory tests was completed within a cohort study design. The testing battery was designed to examine isolated physical and physiological capacities in order to examine this validity. Participants were required to complete the $30\text{-}15_{IFT}$ (to assess PHIR ability), MSFT (estimated $\dot{V}O_2max$), 2000-m time trial (average aerobic speed), 40-m maximal sprint (maximal speed) and 5-0-5 test (COD ability). All participants undertook these tests were at two periods; 1) the beginning of the pre-season phase (following two weeks of pre-conditioning); 2) At the end of the pre-season training period (11 weeks later). Longitudinal analysis across the training period (11 weeks) was limited to 47 participants due to player availability during second the testing period.

Further, due to unforeseen circumstances the 2000-m time trial was not repeated in the second testing period and hence this variable was removed from training period longitudinal analysis.

To further examine the validity of the $30\text{-}15_{IFT}$ within rugby league, a sub-sample of players (n = 9) were selected to undertake assessment of repeated-sprint ability and laboratory assessment of $\dot{V}O_2max$. The $\dot{V}O_2max$ test was conducted 3 days following the final day of the original testing battery, and the repeated speed test was performed after a further two days of recovery. As with the original testing procedure, players were asked to refrain from undertaking any strenuous exercise in the 24-hour period prior to testing. Participants were separated into positional groups for further analysis as follows: outside backs (fullbacks, wingers and centres), adjustables (hookers, halfbacks and five-eights), edge-forwards (back-rowers) and hit-up forwards (props and locks).

Subjects

Sixty-three Australian elite (n=37; 25.0 ± 4.5 y, 98.2 kg ± 9.2 kg, Σ7 skinfolds: 67.7 ± 15.3 mm) and junior-elite Rugby League players (n=26; 19.0 ± 0.6 y, 93.1 kg ± 9.4 kg, Σ7 skinfolds: 75.8 ± 22.4 mm) from a professional rugby league club participated in this study. These participants included professional players competing in the elite Australian NRL competition (n=37), and players competing in the NYC (Under 20's) (n=26). To aid a greater understanding of the specific mesomorphic population and data attained, a sub-sample of players (n=9; 19.3 ± 0.4 y, 95.8 ± 9.1 kg, Σ7 skinfolds: 83.7 ± 17.0 mm) were selected for further testing. All participants underwent medical screening and did not present any contraindications for vigorous exercise. Subjects were informed of the study and gave their written informed consent prior to participation. Parental or guardian consent was obtained before junior players were permitted to participate. The Institutional Human Ethics Committee approved all experimental procedures (HREC no: H-2013-0283).

Procedures

To limit the circadian effect on performance as well as to reduce the effect of external factors (such as heat), the testing procedures were largely performed during the morning period (0900 – 1100 h). The only distinction was the 2000-m time trial, which was performed in the afternoon (1500 – 1700 h). All sessions were performed in temperatures between 20-24°C. Each subject completed testing over 3 separate sessions with at least 48 h recovery between sessions. Anthropometrical measurements (mass, Σ7 skinfolds) were taken on the first testing day prior to participants completing the MSFT. Sprinting ability and COD were assessed during the morning of the second testing day before participants returned to complete the 2000-m time trial in the afternoon, while the $30\text{-}15_{IFT}$ was performed during the morning of the third testing day. During testing, players were required to wear their training clothes and either football boots when testing on grass or enclosed running shoes when testing indoors and on the running track. For appropriate maximal tests ($30\text{-}15_{IFT}$ and MSFT) players wore typical training monitoring equipment (e.g. HR monitors). Players were asked to refrain from undertaking any strenuous exercise in the 24-hour period prior to testing. All the players were accustomed to the procedures involved in the study as they had previously been assessed with the current testing battery. Players performed a familiarisation session during the week proceeding testing, with coaching staff providing procedural advice when necessary.

Anthropometry

Body mass was obtained to the nearest 0.1 kg using electronic scales (Tanita, Kewdale, Australia). Skinfold thickness was measured at seven sites (biceps, triceps, subscapular, suprailiac, abdomen, thigh and calf) using calibrated Harpenden skinfold calipers (British Indicators Ltd, West Sussex, United Kingdom). Percentage body fat was estimated using the equations previously described by Durnin and Womersley (1974). Lean mass index (LMI) was calculated as per methods previously described (Slater, Duthie, Pyne, & Hopkins, 2006).

Aerobic Capacity and Power Measures

Estimated $\dot{V}O_2max$ was assessed through the MSFT as previously reported (Ramsbottom et al., 1988). Average aerobic speed (AAS) was evaluated with a 2000-m time trial (2kmTT). Players were required to complete 5 laps of an outdoor polyurethane and rubber synthetic surface track. Individual AAS (estimated as the average velocity during the test) and total time were used as measures of aerobic power.

Speed and Change of Direction Testing

All sprint and COD times were recorded to the nearest 0.01 second using electronic timing gates (Fusion Sport, Sumner Park, Australia) that possess acceptable reliability (ICC = 0.87-0.96, TE = 1.3%-1.9%) (Gabbett, Kelly, & Sheppard, 2008b). Sprint and acceleration profiles were assessed over three maximal 40-m sprints that were separated by a 3-minute recovery period. Average acceleration (SpAcc) was determined from the 0-10-m split, and maximal linear speed (SpMax) was provided from the 30-40-

m split. The trial selected for analysis was the participant's fastest 40-m split (and corresponding split times) (Gabbett et al., 2008b). Change of direction ability was measured using the 505 agility test as per (Draper & Lancaster, 1985). Participants performed three trials on both their right and left foot, and the fastest recorded trial selected for analysis.

The 30-15 Intermittent Fitness Test

The 30-15_{IFT} used to assess PHIR consists of 30-s shuttle runs interspersed with 15-s periods of passive recovery. The initial running velocity was set at 8 $km{\cdot}h^{-1}$ for the first 30-s run and increased by 0.5 $km{\cdot}h^{-1}$ for every subsequent 45-s stage. Players ran back and forth between two lines set 40 m apart at a pace governed by a pre-recorded beep. This pacing strategy assisted players in regulating their running speed as a short beep sounded as they were to be in the 3-m zones either at each end of the running area, or the mid-line (20-m line). During the 15-s recovery period, each player walked forward to the closest of the three lines [Line A (0-m), Line B (20-m) or Line C (40-m), depending on where the previous stage was completed], in preparation for the next stage. The test was terminated when the player could no longer maintain the imposed running speed or when they were unable to reach a 3-m zone around each line at the moment of the audio signal on three consecutive occasions. If players were unable to complete the stage, then their score was recorded as the stage that they last completed successfully, and the running velocity recorded as their maximal 30-15_{IFT} running velocity (V_{IFT}) (Buchheit, 2008b). Maximal aerobic capacity ($\dot{V}O_2max_{30\text{-}15IFT}$) was estimated as per Buchheit (2008b).

Heart Rate Measurement

Heart rate was recorded during both the MSFT and $30\text{-}15_{IFT}$ of players using a Polar T^2 system using R-R recording (Polar Electro Oy, Finland). Peak HR (HR_{peak}) was recorded as the highest HR recorded during the final 30-s of the test. Due to technical malfunction, some HR data was lost (n=9; representing 14% of data collected). The final HR data presented reflects these changes (n=54).

Additional Sub-Sample Testing

Repeated-sprint ability

Repeated sprint ability was examined using a repeated 20-m sprint test. Players performed 12 maximal efforts over 20-m, with each sprint performed on a 20 second cycle. Each player's total sprint time and percentage decrement was calculated as a reflection of individual repeated sprint ability (Gabbett et al., 2013).

Maximal Oxygen Uptake

A maximal graded continuous running test was performed on an electronic treadmill (Cardiovit 100; Schiller, Baar, Switzerland) where $\dot{V}O_2max$ was determined. All players performed a standardized 5-minute warm-up, and the test began at a running speed of 8 $km{\cdot}h^{-1}$, which was increased by 1 $km{\cdot}h^{-1}$ every 2 minutes until volitional exhaustion. The treadmill grade was set to 1%. After a standard calibration procedure of all apparatus, heart rate and gas exchange parameters (minute ventilation, $\dot{V}O_2max$, CO_2 output) were continuously recorded with a commercially available system (Breath-by-Breath Metabolic Measurement; Sensor Medic MSE, Rungis, France). $\dot{V}O_2max$ was determined by the criteria described by Taylor et al. (1955), and was classed as a plateau in $\dot{V}O_2max$ despite an increase in running speed and HR >90% of the predicted maximal value. The velocity associated with $\dot{V}O_2max$ ($v\dot{V}O_2max$) was the lowest running speed that elicited $\dot{V}O_2max$ (Billat, 2001a).

Statistical Analysis

All data is presented as either mean ± SD or mean difference (or change) with 95% confidence intervals (95% CI) unless otherwise stated. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multi-collinearity. The distribution of each variable was examined using the Shapiro-Wilk normality test, and homogeneity of variance was verified with the Levene test. To investigate the validity of the $30\text{-}15_{IFT}$ a cross sectional analysis was examined from the first testing batter. The degree of association between variables was assessed using Pearson's coefficient correlation. In addition to measures of statistical significance, the following criteria were adopted to interpret the magnitude of the correlation (r) between test measures: <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*. If the confidence limits overlapped zero, small positive and negative values for the magnitude was interpreted as unclear; otherwise, that magnitude was deemed to be the witnessed magnitude (Hopkins, 2004).

In order to determine the combined effect of the chosen variables on $30\text{-}15_{IFT}$ performance, a forward stepwise regression model was employed. A forward model was used in order to identify the fewest variables that could predict V_{IFT}, placing greater practical application to the outcomes. This model was run for all players and then re-run for various positional groups with the same variables entered each time. A forward stepwise was also used to determine the effect of these variable to the change in V_{IFT} over a training period. Due to player availability, this was examined using 47 participants. Coefficients of determinants (R^2) were used to indicate the goodness of the fit of the predictor models with V_{IFT} as the independent variable.

RESULTS

Validity

Descriptive analysis for all variables can be found below in Table 4.1, while Pearson correlations with V_{IFT} are presented in Figures 4.1 and 4.2.

Table 4.1: Descriptive measures (mean ± SD) for all measured variables taken from the testing battery.

Variable	N	Mean	± SD	95% CI
Anthropometry				
Age (y)	63	22.5	4.6	21.4 – 23.6
Mass (kg)	63	96.1	9.6	93.8 – 98.5
Skinfolds (mm)	63	71.1	18.9	66.4 – 75.7
Lean Muscle Index (kg)	63	54.3	5.2	53.0 – 55.5
Speed and Change of Direction				
10-m Speed (s)	63	1.66	0.07	1.65 – 1.68
40-m Speed (s)	63	5.17	0.19	5.13 – 5.22
Average Acceleration ($m \cdot s^{-2}$)	63	3.63	0.29	3.55 – 3.70
Average Maximal Velocity ($m \cdot s^{-1}$)	63	8.88	0.40	8.78 – 8.99
505 test (s)	63	2.33	0.15	2.29 – 2.37
Maximal Aerobic Power				
$30\text{-}15_{IFT}$ ($km \cdot h^{-1}$)	63	18.4	0.9	18.2 – 18.6
$30\text{-}15_{IFT}$ ($\dot{V}O_2max$) ($ml \cdot min^{-1} \cdot kg^{-1}$)	63	50.0	3.2	49.3 – 50.3
$30\text{-}15_{IFT}$ (HR peak) (bpm)	63	196.4	7.0	194.6 – 198.1
MSFT ($\dot{V}O_2max$) ($ml \cdot min^{-1} \cdot kg^{-1}$)	63	51.2	4.1	10.2 – 52.3
2km Time Trial (s)	63	533	43	522 – 543
Average Aerobic Speed (AAS) (2km TT) ($m \cdot s^{-1}$)	63	3.8	0.3	3.7 – 3.9

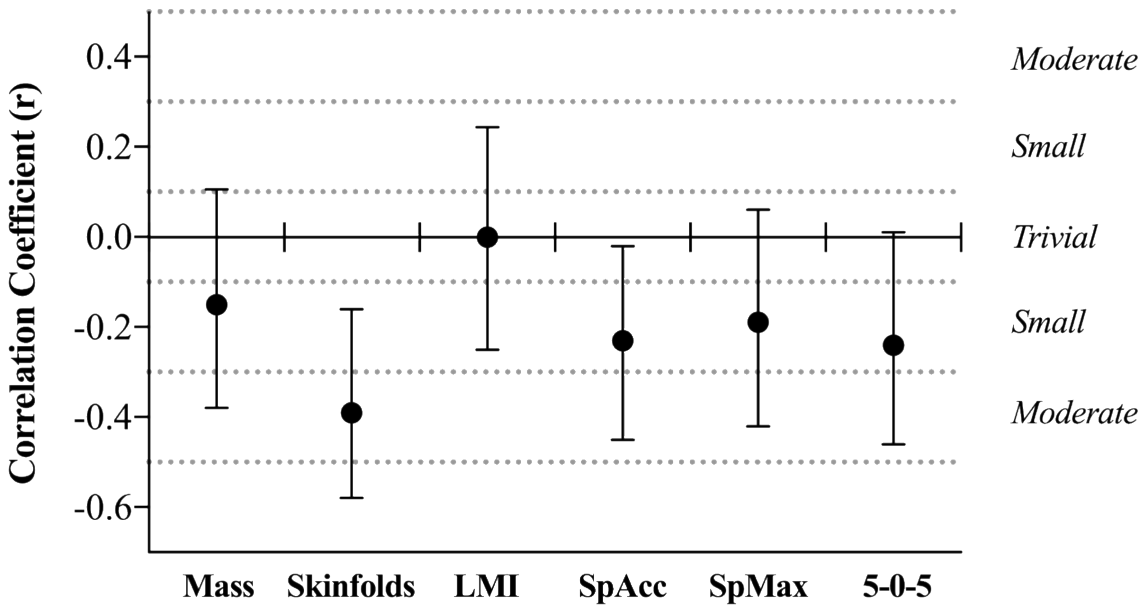

Figure 4.1: Correlations between V_{IFT} and various anthropometrical and physiological measures (mean ± 95% CI) (LMI – Lean Mass Index).

Estimated $\dot{V}O_2max_{30\text{-}15IFT}$ had significant correlations with skinfolds (r = -0.48; *moderate*), Sp10m time (r = 0.36; *moderate*), maximal velocity (r = -0.32; *moderate*), COD ability (r = -0.42; *moderate*) and RSA (% decrement) (r = -0.71; *large*). $\dot{V}O_2max$ (treadmill continuous test) had a significant moderate relationship with estimated $\dot{V}O_2max_{30\text{-}15IFT}$ (r = 0.76; *large*).

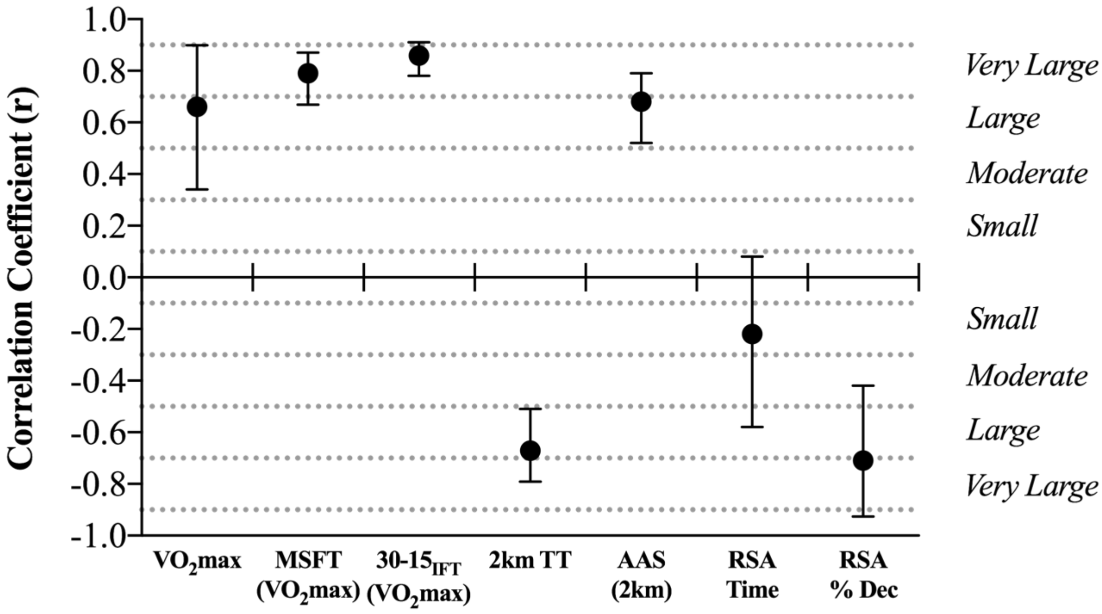

Figure 4.2: The correlations between V_{IFT} and various physiological measures (mean +/- 95% CI) (MSFT –Multi-Stage Fitness Test; AAS – Average Aerobic Speed; RSA –Repeat Speed Ability). * $\dot{V}O_2max$ and RSA tests (n=9).

Physiological Contributing Factors

The stepwise multiple-regression analysis revealed that 71.8% of the adjusted variance in $30\text{-}15_{IFT}$ performance could be explained through a 4 step best fit model. Estimated $\dot{V}O_2max_{MSFT}$ accounted for 61.4% of the variance in $30\text{-}15_{IFT}$ performance. Secondly, AAS revealed another 4.7% of the variance (66.1% total variance). Maximal velocity entered the model third explaining an additional 4.1% (70.2% total variance); whilst the model was completed with lean mass index adding 1.6% of the remaining variance (71.8%). Age, average acceleration and COD ability provided no significant elevation of explained variance in V_{IFT} performance.

Table 4.2: Multiple correlation summary of the deterministic model assuming 30-15$_{IFT}$ (V_{IFT}) as a dependent variable. *

Model	30-15$_{IFT}$ performance (V_{IFT})	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	$\dot{V}O_2max$ #	0.787	0.620	0.614	0.574
2	AAS	0.820	0.672	0.661	0.538
3	SpMax	0.846	0.716	0.702	0.505
4	LMI	0.858	0.737	0.718	0.490

*Step = forward stepwise regression analysis; #Estimated $\dot{V}O_2max$ as per Buchheit (2008b); AAS = average aerobic speed (taken from 2 km time trial); LMI = Lean muscle Index

Various forward stepwise multiple regression analysis of the independent positional groups discovered several predictors of V_{IFT}. Analysis on the outside backs revealed 64% of the variance was accounted for by $\dot{V}O_2max_{MSFT}$ (R^2 = 0.56) and AAS (R^2 = 0.64), adjustables had 82% of the variance explained from AAS (R^2 = 0.68), $\dot{V}O_2max_{MSFT}$ (R^2 = 0.80), COD ability (R^2 = 0.85) and skinfold (R^2 = 0.88), while hit-up forwards revealed 41% of the variance from $\dot{V}O_2max_{MSFT}$ (R^2 = 0.44). When examining the testing variables across a training block, only 25% of the variance could be accounted for from $\Delta\dot{V}O_2max_{MSFT}$ (R^2 = 0.25) suggesting that other physiological adaptations largely contribute to improvements in PHIR ability.

DISCUSSION

The primary findings of this study were: 1) the 30-15_{IFT} is valid test of PHIR among a typically mesomorphic population; 2) whilst this test appears to be simultaneously related to many physiological functions, it is highly aerobic and may be best improved through increased aerobic foundations, and; 3) the physiological contribution of 30-15_{IFT} performance varies between positional groups. Past studies have examined the relationship between V_{IFT} and common field based tests; examining soccer, basketball, European handball and junior athletes in order to establish the validity of the 30-15_{IFT} (Buchheit, 2008b; Buchheit, 2010a; Haydar et al., 2011). However, these studies have utilised participants of relative homogeneity, and few that fit a mesomorphic physique (Delaney, Scott, Ballard, Duthie, Hickmans, Lockie, & Dascombe, 2015b). The main finding of the current study support these previous findings, confirming the validation of the 30-15_{IFT} among a mesomorphic cohort. This study observed strong relationships between V_{IFT} performance and aerobic capacity ($\dot{V}O_2max$; r= 0.63 and $\dot{V}O_2max_{MSFT}$; r= 0.79), aerobic power (2km TT; r= 0.68) and repeat speed ability (RSA_{DEC}; r= -0.71) supporting the construct validity of the 30-15_{IFT} in a previously untested population, while further emphasising the underlying metabolic mechanisms of this test.

In contrast to previous studies (Buchheit, 2008a; Buchheit, 2008b; Perandini, Chimin, Okuno, Lima, Buchheit, & Nakamura, 2009), no significant relationships were observed between V_{IFT} and measures of speed (r= 0.16), acceleration (r= 0.23) and COD ability (r= -0.24). This is likely due to the physiological profile of the athlete cohort assessed. Regardless of playing position, the match play demands of rugby league require players to have proficient speed and power capacities (Baker & Newton, 2008; Gabbett, Jenkins, & Abernethy, 2011a; Sirotic, Coutts, Knowles, & Catterick, 2009; Sirotic et al., 2011). It may be that due to the homogeneity of these capacities in rugby league players, it is more difficult to distinguish PHIR from these specific metabolic processes. Previously, it has been reported that the deceleration, COD and acceleration phases have large metabolic implications in V_{IFT}. It is likely that the current test of supra-maximal COD (505) does not reflect the sub-maximal COD performed during the test (Haydar et al., 2011). Despite this, the significant correlations between BF (Σ7 skinfolds) with V_{IFT} and $\dot{V}O_2max_{30\text{-}15IFT}$ (r= -0.39, moderate; r= -0.51, large) suggest that those with a higher relative body fat (BF%) have a superior metabolic demand placed on them during the numerous COD tasks, which limits their V_{IFT}. Collectively, these correlational findings suggest that while V_{IFT} concurrently relates to many physiological capacities, the extent of these appear to vary from sport to sport, dependant on the individual physiological profile (Buchheit, 2008b; Buchheit et al., 2009a; Darrall-Jones et al., 2015). Given that contact sports such as rugby league, rugby union and American football may have a larger and less homogenous range of body types it appears that these relationships may be less stable. However, it is vital that practitioners understand the holistic athletic profile when choosing to prescribe HIT based off the $30\text{-}15_{IFT}$.

Buchheit (2008b) reported that 75% of the variance of V_{IFT} (r= 0.87) could be explained from CMJ, 10-m sprint time, $\dot{V}O_2max$ and individual heart rate recovery index (HR_{RE}). However, this study did not reveal the extent to which these physiological factors concurrently accounted for V_{IFT}. Moreover, given the differences in the correlational findings of the current study compared to previous work (Buchheit, 2008b; Haydar et al., 2011), the secondary aim was to determine the contribution of traditional physiological attributes to $30\text{-}15_{IFT}$ performance and how these differ among playing position and across a training period. The current study reported that an individual's estimated aerobic capacity ($\dot{V}O_2max_{MSFT}$) was the primary variable in the explanatory model assessing PHIR ability (R^2 = 0.62). Following the theoretical physiological model of the 30-15 test (Buchheit, 2010a), aerobic power (measured from 2km TT time) then contributed an additional 4.7% to the model (R^2 = 0.67). Metabolically, this represents the shift and advantage of a delaying lactate build up and depletion of glycogen stores, which would improve PHIR ability. Yet despite the great aerobic demands of the test, these collective findings confirm past studies that the final velocity is determined through anaerobic sources (Buchheit, 2008a; Buchheit, 2008b; Buchheit, 2010a; Buchheit et al., 2009a).

In contrast to previous theoretical validity, the influence of the negatively correlated maximum velocity (4.1%; R^2 = 0.72) proposes that those with higher maximal velocities possess poorer PHIR ability. However, this is likely to be a reflection of the mesomorphic rugby league cohort and metabolic profile. In theory, a lower MSS would limit an individual's anaerobic velocity reserve (AVR), and subsequently reduce their ability to sustain high-intensity exercise. One suggestion is that due to the aerobic foundations of the test, those players who have better speed qualities possess a greater proportion of fast twitch fibres and potentially lower $v\dot{V}O_2max$. The final 1.6% improvement in the model came from the inclusion of lean mass index (LMI) (R^2 = 0.74). As previously reported, the metabolic and non-metabolic (greater eccentric stress and damage on muscle structures) demands associated with the numerous CODs in the 30-15_{IFT} appear to be accentuated with a greater proportion of relative fat mass. These findings support previous studies (Delaney et al., 2015b) that have suggested that it is beneficial for rugby league athletes to have a greater relative muscle mass when performing COD tasks. Additionally, it is reasonable to suggest that an increased BF% will increase the metabolic demands in running further negating PHIR ability. These findings further support the conceptual validity of the test by reproducing physiological theory on PHIR mechanisms in a newly tested population.

Separately, the current study aimed to both explore the contributing physical qualities to V_{IFT} across positional groups in rugby league as well as further understanding what contributed to changes in V_{IFT} across a pre-season. Due to significant differences in match-play demands (McLellan & Lovell, 2013; Sirotic et al., 2009) and reported PHIR ability (Gabbett et al., 2011b) of positional groups in rugby league, it is not unreasonable to suggest there exists different physiological profiles across these position. Moreover, given the differences in the contributing factors of V_{IFT} in the current study compared to previous studies (Buchheit, 2008b) it appears that V_{IFT} is highly reflective of individual athlete training history. The current findings indicate that whilst all positions exhibit an aerobic base, the extent of this contribution to V_{IFT} is variable. For example, 64% of the variance in outside backs (fullbacks, centres, and wingers) V_{IFT} could be accounted for by aerobic capacity ($\dot{V}O_2max_{MSFT}$) (R^2 = 0.56) and aerobic power (2km TT) (R^2 = 0.64). Given that outside backs have been shown to undertake significantly more sprints (Waldron et al., 2011) as well as cover more high speed- and very high speed-running when compared to other positional groups, these athletes are typically more anaerobically suited. The current physiological tests could best explain the variance in V_{IFT} within the adjustables (hookers, half-backs and five-eighths). Indeed, 82% of V_{IFT} could be accounted for from aerobic power (R^2 = 0.68), aerobic capacity (R^2 = 0.80), supra-maximal COD ability (R^2 = 0.85) and BodyFat (Σ7SF) (R^2 = 0.88). These findings parallel the physiological demands of match-play efforts, where it has been shown adjustables have a high aerobic component, covering a greater distance at moderate to high intensities compared to forwards (Sirotic et al., 2011; Waldron et al., 2011). Kempton et al., (2015b) also observed that adjustables have the greatest acceleration and deceleration demands emphasising the metabolic and non-metabolic efficiency these athletes may have to both sub- and supra-maximal COD. PHIR ability was less predictive for forwards (props, back-rowers and locks), with only 41% of V_{IFT} explained with current tests. This is likely due to the high anaerobic, sub-maximal COD (shuttles) and inter-effort recovery ability which is specific to these playing positions. Within match-play, forwards are required to complete significantly more repeated high-intensity efforts (accelerations, high speed or contact efforts with less than 21 s of recovery) per minute of match play than adjustables and outside backs (Austin et al., 2011). Unfortunately, a clear test of anaerobic capacity was not used in the battery, potentially limiting the explained variance in this group. Collectively, these findings demonstrate the discrete nature and contributing factors of V_{IFT} across positional groups in rugby league, further demonstrating the conceptual validity to use this test across all populations.

Due to the importance of individual athlete HIT programming it is vital to understand how V_{IFT} changes (ΔV_{IFT}) in response to a pre-season training regime (12 weeks). Interestingly, only 25% of the variance (aerobic capacity; $\dot{V}O_2max_{MSFT}$) in ΔV_{IFT} (R^2 = 0.25) could be explained through the current testing protocols. This is perhaps due to the modality of training performed across this period and in particular the final weeks. Due to the match-play demands of rugby league, as the competition phase comes near training often switches from more aerobic based conditioning to anaerobic emphasised training incorporating many CODs. It may be that the most dominant changes in V_{IFT}

across a pre-season are contributed via anaerobic adaptation, improvement in sub-maximal COD and inter-effort recovery ability. One limitation of this study was the broad testing battery used. Unfortunately in an elite team sport setting, it is often difficult to test for all physiological variables, and whilst the RSA test showed large correlations with V_{IFT}, it was only performed on a sub-sample of athletes (n=9). Performing this on the whole testing group may have given greater insight into the contribution of anaerobic capacity and inter-effort recovery ability. Nonetheless, these findings provide further support to suggest V_{IFT} is representative of numerous physiological capacities. Based on these findings and in agreeance with Buchheit (2008b), performance staff should aim to profile their athletes with other tests before prescribing HIT based from the 30-15_{IFT}, providing greater insight into the physiological strengths and weaknesses of their athletes.

LIMITATIONS

Whilst an aim of the current study was to explain the contributing factors to PHIR capacity in rugby league athletes, it may be noted the sample is too low to have a strong predictive capacity and therefore is primary a descriptive finding. In addition, future research may implement an automated regression model to overcome some limitation in the current forward stepwise regression model. Similarly, findings from the sub sample analysed (n=9) should be interrupted with these limitations in mind. Future research may aim at replicating the current study design with a greater population.

PRACTICAL APPLICATIONS

The current findings demonstrate the validity and contributing physiological factors to 30-15_{IFT} performance within a mesomorphic rugby league population, establishing individual aerobic function as a primary determinant of the 30-15_{IFT} and the most sensitive to improvement. Given the complexity of the physiological responses to HIT and the recent growth in the use of the 30-15_{IFT} (Buchheit, 2010a; Darrall-Jones et al., 2015) to examine PHIR and prescribe HIT in team sports (such as rugby league and rugby union), these contributing factors of V_{IFT} among a mesomorphic population need to be examined. However, the results also confirm previous research suggesting the final stages of the 30-15_{IFT} are highly dependent on anaerobic metabolism. Collectively, the demands of the 30-15_{IFT} appear highly specific to the physiological profile of the athlete, while V_{IFT} is simultaneously impacted many physiological variables, which may differ between sports. As such, it is important for practitioners to understand how the physiological profile of their athlete affects PHIR and therefore prescribe HIT with this in mind.

Chapter V

Running momentum: a new method to quantify prolonged high-intensity intermittent running performance in collision sports

This chapter is based on the peer-reviewed paper ***accepted and published*** in Medicine and Science in Football:

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ABSTRACT

This study determined differences in prolonged high-intensity running (PHIR) performance and running momentum (p_{IFT}) between competition levels and positional groups in rugby league. Elite Australian National Rugby League (NRL), sub-elite [state-based competition (SRL); national youth competition (NYC); local league (LL)] and junior-elite (U18; U16) rugby league players completed the 30-15 Intermittent Fitness Test (30-15_{IFT}) to quantify PHIR performance. Final running momentum (p_{IFT}; kg·m·s^{-1}) was calculated as the product of body mass and final running velocity ($V_{IFT;}$ m·s^{-1}). Effect sizes were used to examine between-group differences. 30-15_{IFT} performance was *possibly* to *likely* higher in NRL players (19.5 ± 1.0 km·h^{-1}; mean ± SD) when compared to SRL (ES= 0.6 ± 0.5; ES ± CI), NYC (ES = 0.6 ± 0.5) and U18 (ES = 0.8 ± 0.5) players. NRL players (537 ± 41 kg·m·s^{-1}) possessed *possibly* to *very likely* greater p_{IFT} than SRL (ES = 0.7 ± 0.5), NYC (ES = 1.2 ± 0.5), U18 (ES = 2.3 ± 0.6), U16 (ES = 3.0 ± 0.7) and LL players (ES = 2.0 ± 0.7). Middle forwards attained a *likely* superior p_{IFT} (ES = 0.5−1.8) to all other positional groups. This study demonstrated that elite rugby league players possess superior PHIR capacities, while highlighting that p_{IFT} can account for the disparities in body mass between groups.

Keywords:

30-15 Intermittent Fitness Test, HIT, testing, football

INTRODUCTION

Most team sports require players to complete periods of prolonged high-intensity intermittent running (PHIR) during match-play (Bangsbo, 2000a). In collision-based sports, such PHIR activity is often punctuated by forceful tackles and highly demanding eccentric muscular activities (i.e. decelerating and jumping). For example, rugby league competition is characterised by intermittent bouts of high-intensity activity that incorporates HIR, repeated accelerations, COD and intense physical collisions (Gabbett, 2012; Johnston et al., 2014; Sirotic et al., 2011). Since the activity profile of most team sports like rugby league are largely acyclic in nature and require these intense activities (e.g. HIR, COD) at varying speeds, the energy supply for muscular effort are derived from both aerobic and anaerobic sources (Bangsbo et al., 2007; Bangsbo et al., 2006). Consequently, the capability to perform PHIR combined with repeated high-intensity efforts (including sprint and tackles) is seen to be central to success (Austin et al., 2011; Austin & Kelly, 2014; Gabbett & Gahan, 2016). For example, it has been demonstrated that these high-intensity efforts occur at decisive moments during match-play in rugby league, helping to differentiate between successful and non-successful teams, further highlighting their importance (Austin et al., 2011; Gabbett & Gahan, 2016).

The 30-15$_{IFT}$ has been shown as a valid, reliable and practical alternative (see *Chapter III and IV*) to quantify PHIR capacity in team sport athletes when compared to commonly used aerobic based field tests (e.g. Yo-Yo Intermittent Recovery Test, Multi-Stage Fitness Test) (Buchheit, 2010a; Buchheit et al., 2009b; Mosey, 2009). The 30-15$_{IFT}$ incorporates and examines several physiological capacities associated within team sports performance (including individual inter-effort recovery, COD ability, aerobic capacity and ASR) (described in *Chapter IV* of this thesis) (Buchheit, 2008b; Haydar et al., 2011;

Scott et al., 2015). At termination, V_{IFT} may be used to prescribe HIT (Buchheit, 2008b). However, whilst the 30-15_{IFT} may be an appropriate to assess PHIR capacity that require anthropometric homogeneity, it may have limitations in collision sports. Currently, this test does not directly take into account the discrepancy of individual physical characteristics such as body mass between individual athletes.

It has been suggested that a higher body mass is beneficial for collision sport athletes, due to the proportional increase in momentum they may achieve prior to contact (Barr, Sheppard, Gabbett, & Newton, 2014; Duthie, 2006). However, an increased body mass results in greater inertia during running, requiring more force to decelerate during the braking phase of a change of direction task (Enoka, 2002). This increased force may apply greater mechanical and metabolic stress during shuttle running activities such as the 30-15_{IFT}, negatively impacting on an individual's final result (Buchheit et al., 2009a; Haydar et al., 2011). The interaction between body mass and PHIR is critical for collision sports, as both are often viewed as important factors in match performance (Gabbett, Kelly, & Pezet, 2008a; Sirotic et al., 2011). For example, it has been demonstrated that individual sprinting force (mass × 10-m acceleration) relates better to successful ball carries in rugby league than sprint speed or acceleration qualities alone (Waldron, Worsfold, Twist, & Lamb, 2014a; Waldron, Worsfold, Twist, & Lamb, 2014b), indicating the inclusion of mass plays a significant role in physical match-specific tasks. However, whilst it has been shown that relative power production is important to match play performance, little is known on the effect of body mass to the mixed aerobic-anaerobic demands of collision sports (McLellan & Lovell, 2013; Waldron et al., 2011).

It has recently been reported that PHIR performance (V_{IFT}) remains relatively stable from U16 to senior rugby union players, despite a continued increase in body mass (Darrall-Jones et al., 2015). Due to these findings it has been suggested that by monitoring the interaction of body mass and PHIR performance, a more sensitive change in PHIR may be determined for collision-based athletes (Darrall-Jones et al., 2015). However, currently there is not a commonly reported measure in team sports to examine this interaction. As most team sports have varying physical positional demands (Bangsbo, 1994; Duthie, 2006; Sirotic et al., 2011), understanding the interaction between changes in body mass and PHIR performance may assist practitioners in tracking the physical development of athletes longitudinally. These varying physical demands often reflect greater heterogeneous physical and anthropometrical qualities across playing squads, which make between-position comparisons in PHIR performance difficult. Importantly, depending on the sport, these interactions may distinguish positional groups and levels of competition.

It is often accepted that elite team sport athletes are required to develop greater physiological attributes than sub-elite athletes in order to be successful (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010; Pyne et al., 2005; Rampinini et al., 2007a). However, whilst aerobic capacity has substantially differentiated levels of competition in rugby league (Gabbett et al., 2011b) only trivial differences in PHIR performance have been observed when comparing elite players with both sub-elite (1.4% mean difference) and junior-elite (1.3%) players during a 12-s maximal repeated sprint-shuttle test (Gabbett, 2013; Gabbett et al., 2011b). These results may reflect the maximal sprint-shuttle nature and work to rest durations (1:3) of the test protocol, thus eliciting a higher reliance on anaerobic metabolism than the mixed aerobic-anaerobic profile that is more representative of team-sports activity (Austin et al., 2011; Bangsbo, 1994; Johnston et al., 2014). Further, the 12-s maximal shuttle sprint test has been reported to have a typical error of 4.3% (Gabbett et al., 2011a). Whilst this typical error is considered as *good* reliability, the error is higher than the 1.9% reported for the 30-15_{IFT}, which may better reflect the mixed aerobic and anaerobic contribution of PHIR in teams sports.

It has been demonstrated that elite-NRL players possess superior physiological capacities when compared to SRL players (including aerobic capacity, speed and lower body power), with suggestions these qualities are important to match-play performance (Gabbett et al., 2011b). However, these physiological differences are yet to be observed during PHIR performance. Further, unlike other team sports, the large contact loads in these sports mean that PHIR may not purely reflect the demands and requirements of the sport. Due to the heterogeneity in anthropometrical qualities, perhaps the inclusion of body mass that may better distinguish these athletes as previously suggested. Indeed, past authors have demonstrated that there is a substantial effect of body mass and PHIR in rugby union players (Darrall-Jones et al., 2015). As such, the calculation of this interaction may better differentiate between levels of competition and positional groups than V_{IFT} in isolation. Such a variable would provide a new and novel method associated to PHIR performance. Therefore, this study aimed to determine if an introduced calculation of PHIR 'final momentum' (p_{IFT}) may better distinguish levels of competition and positional groups than traditional velocity-based measures (V_{IFT}). Additionally, this study aimed to investigate if there were any differences in V_{IFT} between elite, sub-elite and junior-elite players, given only trivial differences in PHIR performance have been previously observed.

METHODS

Participants

Elite, sub-elite and junior elite male rugby league cohorts from a professional National Rugby League (NRL) club (n=136) were recruited to participate in this study. Players competed in either the National Rugby League (NRL, n=22; 27 ± 4 y, 100.1 ± 8.7 kg), sub-elite state-based competition (SRL, n=23; 26 ± 4 y, 96.5 ± 11.5 kg), National Youth Competition (NYC, n=28; 19 ± 1 y, 92.3 ± 11.3 kg), local country rugby league competition (Local League [LL], n=22; 25 ± 2 y, 93.7 ± 13.6 kg) as well as players competing in state-level under 18 (U18, n=21; 17 ± 1 y, 86.9 ± 11.2 kg) and state-level under 16 (U16, n=20; 15 ± 1 y, 78.2 ± 10.9 kg) competition. NRL, SRL and NYC players were then pooled to report positional differences of professional rugby league players. All participants underwent medical screening and did not present any contraindications for vigorous exercise. Participants were informed of the study and gave written informed consent prior to participation. Parental or guardian consent was obtained for players under eighteen years of age. The University of Newcastle Human Research Ethics committee approved the study methods (HREC no: H-2013-0283).

Design

In order to examine the influence of body mass on PHIR, the current study developed a new method, calculating the final momentum of the athlete at the completion of the 30-15_{IFT} (p_{IFT} - as the product of an individuals' body mass and final running velocity [$m \cdot s^{-1}$] during the 30-15_{IFT}). To investigate the usefulness of p_{IFT} to quantify PHIR ability in team sport athletes, all participants were required to complete the 30-15_{IFT}. To limit the circadian effect on performance, each playing group performed the testing procedure at times when their regular training was scheduled. Two weeks prior to testing, participants underwent a familiarisation session so they were aware of the running patterns and audio signals of the 30-15_{IFT}. Data were analysed between the identified playing groups as well as between positional groups including: outside backs (fullbacks, wingers and centres), adjustables (hookers, halfbacks and five-eights), edge-forwards (back-rowers) and middle forwards (props and locks).

Methodology

30-15 Intermittent Fitness Test

The 30-15_{IFT} was performed, as previously described by Buchheit (2008b), on a grass oval in temperatures between 20-24°C. Players wore their typical training attire and football boots to ensure ecological validity. Nutritional and hydration strategies were implemented as per the club guidelines, with players refraining from undertaking strenuous exercise or taking stimulants for 24-h prior to testing. Briefly, the 30-15_{IFT} consists of 30-s shuttle runs interspersed with 15-s periods of passive recovery. The initial running velocity was set at 8 $km{\cdot}h^{-1}$ for the first 30-s run after which it increased by 0.5 $km{\cdot}h^{-1}$ for every subsequent 45-s stage. During the 30-s run effort, players ran back and forth between two lines set 40-m apart at a pace governed by a pre-recorded beep, before walking to the nearest line during the 15-s recovery period in preparation for the next stage. The test ended when a player could no longer maintain the imposed running speed or when they were unable to reach a 3-m zone around each line at the moment of the audio signal on three consecutive occasions. If players were unable to complete the stage, their score was recorded as the last stage that they had completed successfully. V_{IFT} was recorded as their maximal 30-15_{IFT} running speed in $km{\cdot}hr^{-1}$

(Buchheit, 2005b; Buchheit, 2008b). As demonstrated earlier in *Chapters III and IV* of the current thesis, V_{IFT} is a valid and reliable measure of PHIR performance in a similar rugby league population (Scott et al., 2015; Scott, Duthie, Delaney, Sanctuary, Ballard, Hickmans, & Dascombe, 2016c). Final 30-15$_{IFT}$ momentum (p_{IFT}) was calculated as a new novel indicator of PHIR performance as: p_{IFT} ($kg \cdot m \cdot s^{-1}$) = body mass (kg) x V_{IFT} (converted to $m \cdot s^{-1}$) . Using a test-retest method design within 3 days, a reliability analysis was performed in a sub-sample of rugby league players (n=55) which demonstrated *good* reliability of this new measure (CV: 1.9%; TE: 9.5 $kg \cdot m \cdot s^{1}$).

Statistical Analysis

Prior to statistical analyses, assumptions of normality were tested using the Shapiro-Wilk test, and data were log transformed where necessary. Effect sizes (ES) and 90% CI were used to describe the magnitude of difference, interpreted as; ES <0.20 trivial, 0.21 – 0.6 small, 0.61 – 1.2 moderate, 1.21 – 2.0 large and >2.1 very large (Hopkins, Marshall, Batterham, & Hanin, 2009). Furthermore, the likelihood of the observed effect was established using a progressive magnitude based approach, 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 (Hopkins, 2007). A customised spreadsheet was used to calculate confidence limits and magnitude-based inferences from *p* values (Hopkins, 2007).

RESULTS

Levels of Competition Differences

Figure 5.1 shows the raw data (pooled mean values) in V_{IFT} and p_{IFT} across the NRL, SRL, NYC, U18, U16 and LL cohorts presented as a box plot. Differences in both V_{IFT} and p_{IFT} between NRL and lower levels of competition are presented in Figure 5.2. 30-15$_{IFT}$ performance was *possibly* to *likely* higher in NRL players (mean ± SD; 19.5 ± 1.0 $km \cdot h^{-1}$) when compared to SRL (ES= 0.6 ± 0.5), NYC (ES = 0.6 ± 0.5) and U18 (ES = 0.8 ± 0.5) players. NRL players (537 ± 41 $kg \cdot m \cdot s^{-1}$) possessed *possibly* to *very likely* greater p_{IFT} than SRL (ES = 0.7 ± 0.5), NYC (ES = 1.2 ± 0.5), U18 (ES = 2.3 ± 0.6), U16 (ES = 3.0 ± 0.7) and LL players (ES = 2.0 ± 0.7). Figure 5.3 displays a comparison of V_{IFT} and p_{IFT} across lower levels of competition.

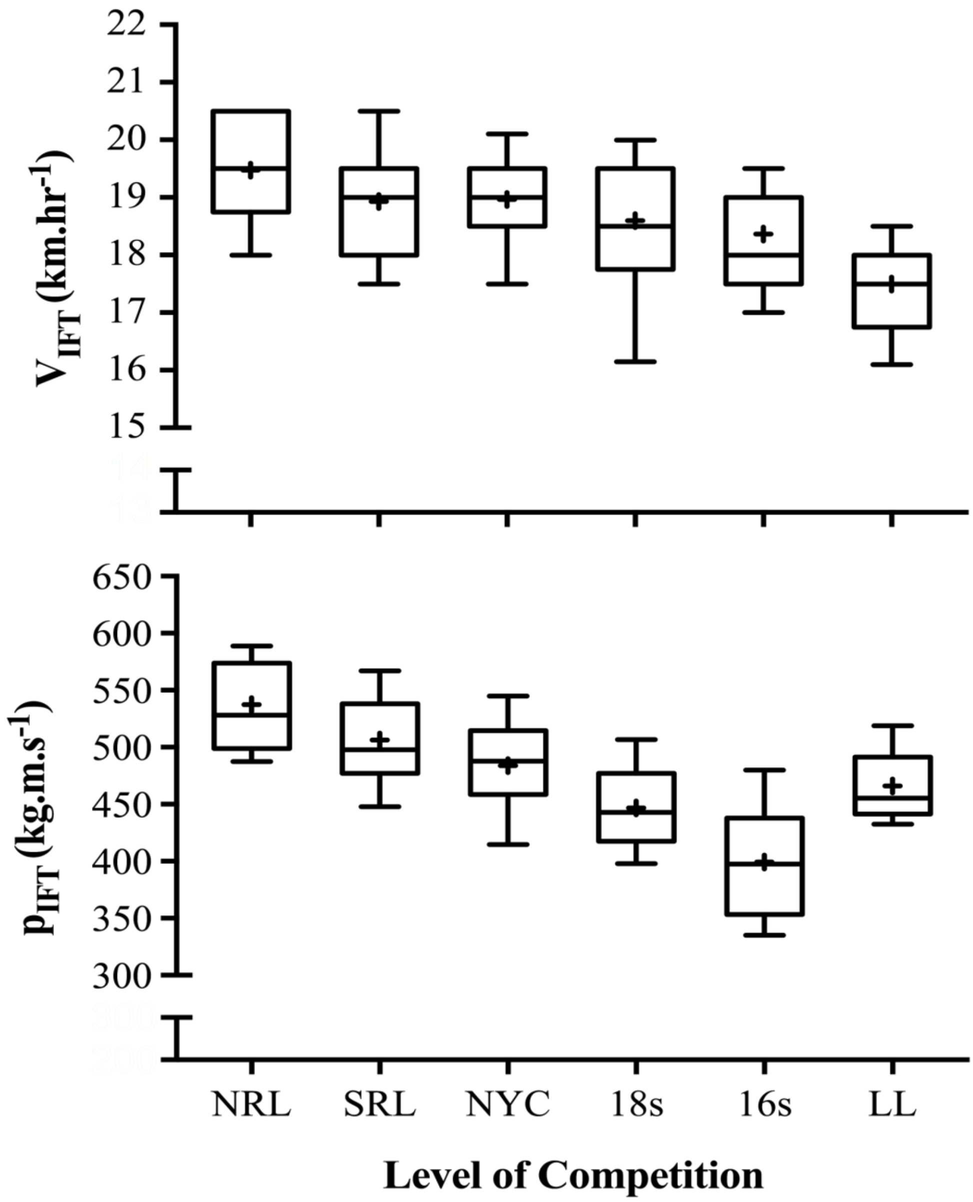

Figure 5.1: Box plots of 30-15$_{IFT}$ performance (V_{IFT}) and final 30-15$_{IFT}$ running momentum (p_{IFT}) for the different rugby league competition levels. Solid line is median, + represents the mean. Whiskers above and below the box indicate the 90th and 10th percentiles. NRL: National Rugby League players; SRL: state-based rugby league players; NYC: National Youth Competition payers; 18s: state-level under 18 players; U16: state-level under 16 players; LL: local country rugby league competition players.

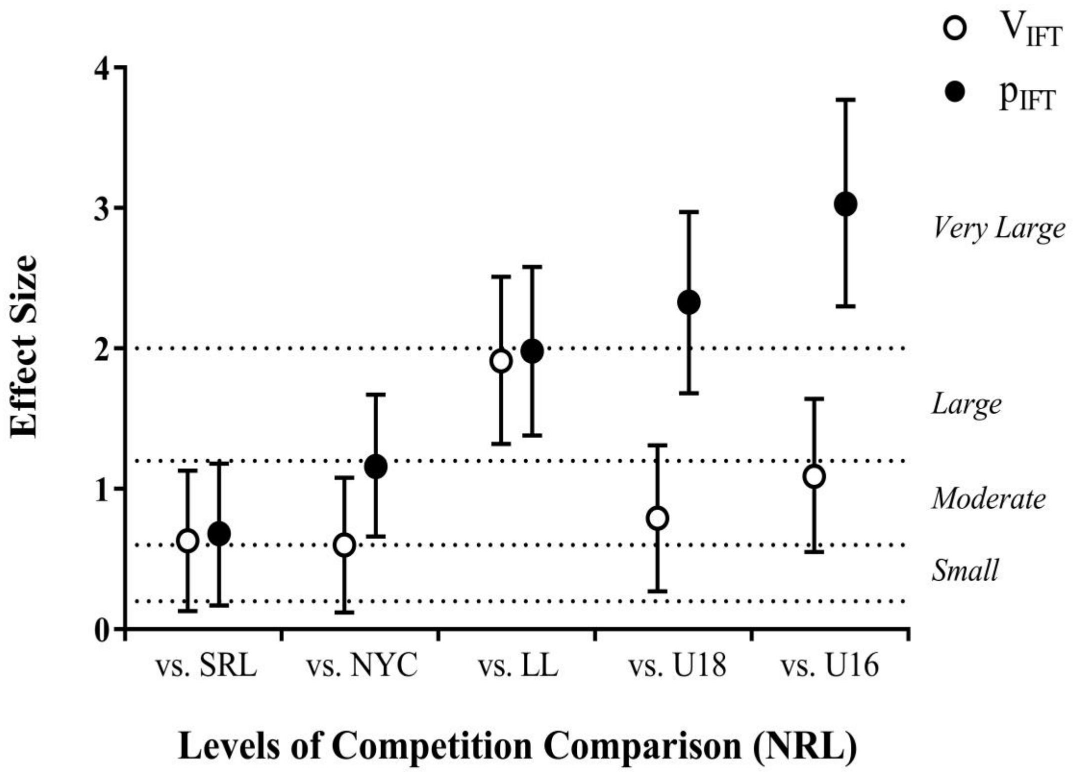

Figure 5.2: Differences in 30-15$_{IFT}$ performance (V_{IFT}) and final 30-15$_{IFT}$ running momentum (P_{IFT}) between NRL and other levels of competition. Values presented as standardised effects (effect size ± 90% CI). NRL: National Rugby League players; SRL: state-based rugby league players; NYC: National Youth Competition players; 18s: state-level under 18 players; U16: state-level under 16 players; LL: local country rugby league competition players.

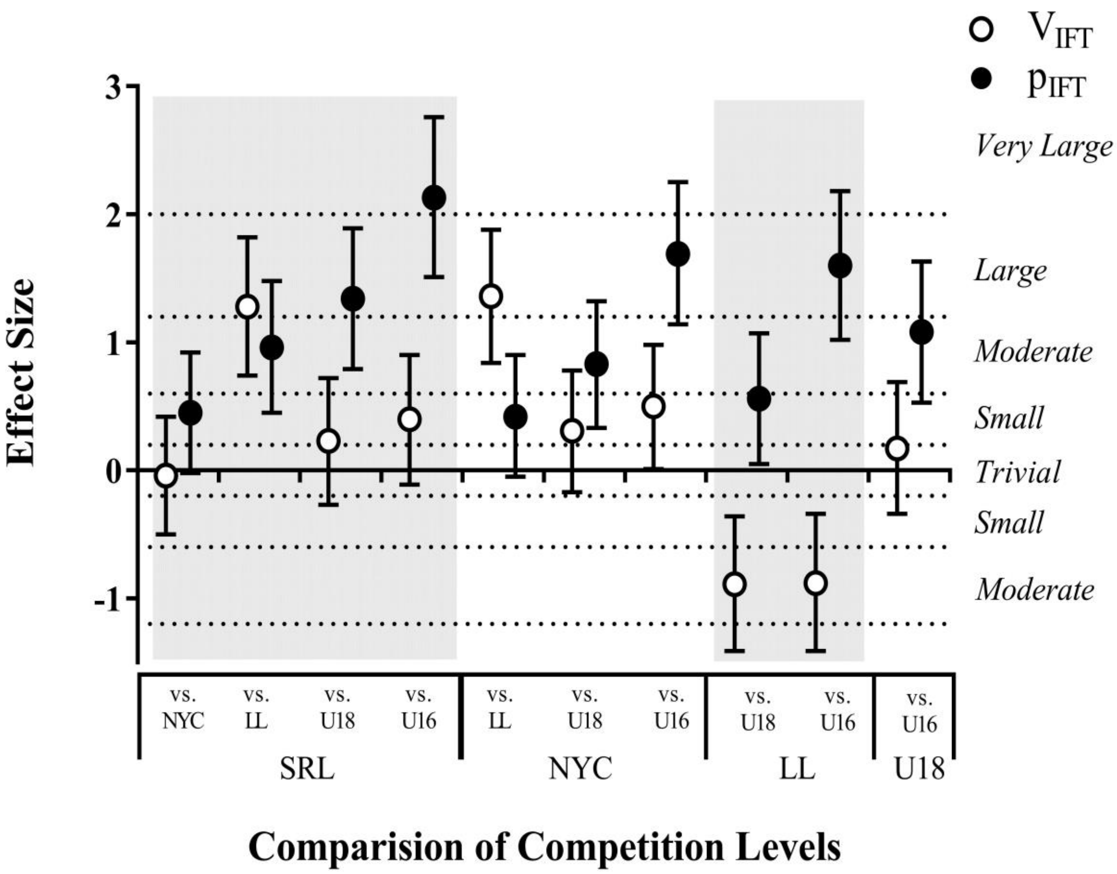

Figure 5.3: Differences in 30-15$_{IFT}$ performance (V_{IFT}) and final 30-15$_{IFT}$ running momentum (P_{IFT}) between lower levels of competition. Values presented as standardised effects (effect size ± 90% CI). NRL: National Rugby League players; SRL: state-based rugby league players; NYC: National Youth Competition players; 18s: state-level under 18 players; U16: state-level under 16 players; LL: local country rugby league competition players.

Positional Differences

NRL, SRL and NYC players were pooled to report positional differences of professional rugby league players (n = 73). Effect sizes between positional groups are presented below in Figure 5.4. 30-15$_{IFT}$ performance was *likely* higher for adjustables and edge forwards when compared to middle forwards (ES = 1.3 ± 0.6 and 1.2 ± 0.6, respectively). Middle forwards attained a *likely* superior p_{IFT} (ES = 0.5−1.8) to all other positional groups.

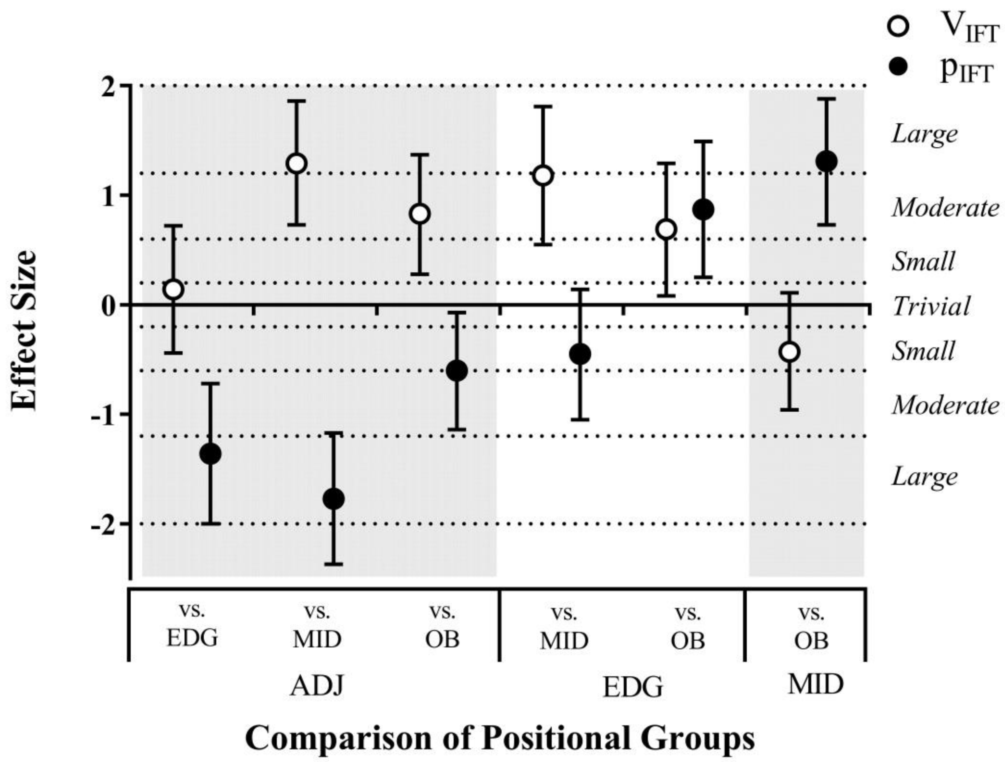

Figure 5.4: Differences in 30-15$_{IFT}$ performance (V_{IFT}) and final 30-15$_{IFT}$ running momentum (P_{IFT}) across rugby league positional groups. Values are as standardised effects (effect size ± 90% CI). ADJ: Adjustables; EDG: Edge forwards; MID: Middle forwards; OB: Outside Backs.

DISCUSSION

The primary aim of the study was to investigate the efficacy of a novel approach to quantify PHIR performance in collision based sports. The current study observed *likely* to *very likely* increases in final momentum attained at the completion of the 30-15$_{IFT}$ (p_{IFT}) between NRL and NYC, LL, U18 and U16, as well as between positional groups. Importantly, these findings provide further evidence that this new method may better distinguish PHIR performance of heterogeneous squads than velocity-based values in isolation. Given recent studies (Gabbett, 2013; Gabbett et al., 2011b) have reported minimal differences in PHIR performance across levels of competition, incorporating the interaction of body mass with PHIR may provide practitioners with a separate indictor of PHIR performance with greater application in collision sports. Additionally, this study aimed to investigate whether any differences existed in V_{IFT} between elite, sub-elite and junior-elite players, as only trivial differences in PHIR performance has previously been observed (Gabbett, 2013; Gabbett et al., 2011b). The current study found NRL players possessed *possibly* to *likely* greater V_{IFT} than all other levels of competition, signifying the superior PHIR required at the elite level. Collectively these findings confirm that physical and physiological differences exist between levels of competition. In addition, due to the greater differences in p_{IFT} witnessed across competition levels, the data suggests that $p_{IFT,}$ and not simply $V_{IFT,}$ presents a more appropriate and holistic method of quantifying PHIR in collision sport athletes (Darrall-Jones et al., 2015).

This investigation found that the calculation of momentum (p_{IFT} - as the product of an individual's body mass and final running velocity [$m{\cdot}s^{-1}$] during the 30-15$_{IFT}$) discriminated between physical differences in PHIR ability between competition levels.

As highlighted previously (including above in *Chapter IV*), an increased body mass is desirable in collision sports (Barr et al., 2014), despite perhaps being detrimental on PHIR performance (Darrall-Jones et al., 2015; Scott et al., 2016c). Specifically, an increase in lean muscle mass may improve running momentum whilst potentially improving the muscular efficiency of movement patterns common to team sports (Delaney et al., 2015b; Delaney, Thornton, Scott, Ballard, Duthie, Wood, & Dascombe, 2015c). Darrall-Jones et al. (2015) recently suggested that maintaining V_{IFT} while increasing individual body mass is *very likely* to *almost certainly* to increase V_{IFT} (or more appropriately, greater p_{IFT}) in rugby union players. The current study supports these observations, as it demonstrated much larger differences in p_{IFT} than in V_{IFT} between playing levels. For example, NRL players exhibited substantially superior p_{IFT} than both U16 and U18 players, whilst only demonstrating a moderately higher V_{IFT}. These findings demonstrate that changes in p_{IFT} may better monitor an individual's PHIR performance and longitudinal athletic development than V_{IFT} alone.

The current study also examined whether p_{IFT} could differentiate between positional groups, given the disparity observed in body mass in rugby league players due to diverse physical requirements during match-play (Gabbett et al., 2008a). In comparison to V_{IFT}, middle forwards demonstrated a superior (small to large differences) p_{IFT} than the other playing groups. Given the importance of collisions for middle forwards, it is highly advantageous for these players to have a greater momentum, whilst maintaining PHIR performance. However, it is important to consider how greater body mass influences running momentum. Previous studies have suggested that rugby league players benefit from a greater relative muscle mass when performing changes of direction

(Delaney et al., 2015b). Conversley, it is reasonable to assume that the metabolic and mechanical (greater eccentric stress and damage on muscle structures) demands are increased with a greater proportion of relative fat mass during the change of direction phases of PHIR efforts. Typically, middle forwards have both a greater body mass and relative fat mass than other positional groups, which is predominately to increase the momentum of these athletes into collisions (Baker & Newton, 2008; Barr et al., 2014). While this study supports the observation of an increased momentum, ideally an athlete should aim to concurrently improve p_{IFT} and V_{IFT}. To facilitate this, collision sport athletes should aim to improve their underlying physiological qualities while increasing lean muscle mass to improve both running momentum and PHIR performance.

While substantial differences were evident in V_{IFT} between NRL and lower levels of competition, only small differences were present in V_{IFT} when comparing the SRL and NYC to the U18 and U16 playing levels. The greater differences reported in the elite level competition is likely to reflect the difference in training loads between full-time elite players with part-time sub-elite and lower league players. Over the past decade, the evolution of strength and conditioning practices have greatly improved the physical capacities of elite rugby league players (Johnston et al., 2014), with these players undertaking substantially more training focused on developing these specific physiological capacities, such as PHIR performance (Scott et al., 2016c). While training loads were not monitored for all groups in the current study, elite rugby league players in the current study completed ~520 minutes of training a week, which is considerably more than the ~350 minutes per week previously reported for sub-elite players (Morgan & Callister, 2011). Collectively these findings demonstrate a difference in the PHIR performance of NRL elite rugby league players compared with their lower league counterparts. Additionally, these results reinforce the need for extremely well developed PHIR capacities for elite rugby league performance.

Finally, this study aimed to determine whether PHIR performance (V_{IFT}) differed between positional groups, given the well documented variation in match-play demands (Sirotic et al., 2009; Waldron et al., 2011), and the disparity in anthropometrical dimensions (Gabbett et al., 2008a). The current study revealed *likely* large differences in V_{IFT} when comparing adjustables and edge forwards to the middle forwards. The greater V_{IFT} reported for the adjustable and edge forwards reflects the previously demonstrated greater PHIR demands of these positions compared to middle forwards during match-play (Kempton et al., 2015b; Sirotic et al., 2011; Waldron et al., 2011). In addition, the moderately poorer PHIR performance reported for outside backs (compared to edge forwards and adjustables) reflects observations that outside backs are required to demonstrate greater sprint and anaerobic qualities than other positional groups (Sirotic et al., 2011; Waldron et al., 2011). Whilst the 30-15_{IFT} examines both aerobic and anaerobic capacities, *Chapter IV* reported the strong aerobic foundation observed in a similar rugby league cohort (explaining 66% of V_{IFT} variance) (Scott et al., 2016c). Indeed, *Chapter IV* demonstrated that adjustables and edge forwards rely more heavily on aerobic capabilities throughout the 30-15_{IFT}, as opposed to outside backs and middle forwards who utilise an increased anaerobic contribution (Scott et al., 2016c). Given the greater aerobic capabilities of adjustables and edge forwards, it is likely that these qualities enhance PHIR performance. Taken together, these results are the first to demonstrate that PHIR performance (as defined from p_{IFT} and V_{IFT}) can distinguish between positional groups in rugby league.

CONCLUSIONS

This study provides the first examination of p_{IFT} as a function of PHIR performance, revealing it to be a reliable and separate indicator that is highly useful in collision-based sports. This study suggests that p_{IFT} may be a separate indicator of physical performance in sports that demonstrate heterogeneity in body size. This analysis may be useful when monitoring an individual over time as they may experience large changes in body mass due to morphological adaptation. Separately, this study provides evidence that elite rugby league players possess physiological capacities that allow for a superior PHIR performance than either sub-elite or junior-elite players. It has also been shown that PHIR performance varies across playing position, in accordance with match-play and training demands. Taken together, these findings provide evidence for individual specific conditioning programs that aim to improve the physical qualities related to match demands such as PHIR performance. Future research may aim at examining how these qualities relate to match-play performance in collision-based sports.

PRACTICAL APPLICATIONS

The current study establishes the use of the p_{IFT} and V_{IFT} from the 30-15$_{IFT}$ as an index of PHIR performance to distinguish between levels of competition and positional groups in rugby league. Further, the 30-15$_{IFT}$ may provide a suitable test to examine more specific elements of PHIR performance in collision sports. The calculation of p_{IFT} provides a new novel and meaningful way to express the inter-play of body mass and PHIR performance in mesomorphic athletes. It is suggested that p_{IFT} should be used independently of V_{IFT}, as it references the ability to overcome the prolonged inertial effect of PHIR rather than representing the specific physiological capacities incorporated in V_{IFT}. Additionally, p_{IFT} may provide an informative tool to monitor longitudinal PHIR performance in collision sports, due to large changes in body mass during physical development.

Chapter VI

Differences between relative and absolute speed and metabolic thresholds in rugby league

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ABSTRACT

This study compared relative and absolute speed and metabolic thresholds for quantifying match output in elite rugby league. Twenty-six professional players competing in the National Rugby League (NRL) were monitored with global positioning system (GPS) devices across a rugby league season. Absolute speed [moderate-intensity running (MIR_{Th} >3.6 $m{\cdot}s^{-1}$); high intensity running (HIR_{Th} > 5.2 $m{\cdot}s^{-1}$)] and metabolic (>20 $W{\cdot}kg^{-1}$) thresholds were compared to individualised ventilatory [first (VT_{1IFT}), and second (VT_{2IFT})] thresholds estimated from the $30\text{-}15_{IFT}$, as well as the metabolic threshold associated with VT_{2IFT} (HP_{metVT2}), to examine difference in match-play demands. VT_{2IFT} mean values represent a 146%, 138%, 167% and 144% increase in the HIR dose across adjustables, edge forwards, middle forwards and outside backs. Distance covered above VT_{2IFT} was *almost certainly* greater (ES range = 0.79 – 1.03) than absolute thresholds across all positions. Trivial to small differences were observed between both VT_{1IFT} and MIR, while small to moderate differences were reported between HP_{metVT2} and HP_{metTh}. These results reveal that the speed at which players begin to run at higher intensities is dependent on individual capacities and attributes. As such, using absolute HIR speed thresholds underestimates the physical HIR load. Moreover, absolute MIR and high metabolic thresholds may over- or under- estimate the work undertaken above these thresholds depending on the respective fitness of the individual. Therefore, using relative thresholds allows for better prescription and monitoring of external training loads based on measured individual physical capacities.

Keywords: 30-15 Intermittent Fitness Test, global positioning systems, team sports

INTRODUCTION

Advancements in technology have led to the extensive implementation of GPS and microtechnology within team sports to quantify movement demands. The ability to more reliably quantify and interpret these demands has led to a greater understanding of the external loads experienced by athletes during training and match-play, albeit with noted limitations (Scott et al., 2016b). Ultimately, such methods provide performance staff with greater capacity to monitor athletes training loads and prescribe field conditioning, increasing the specificity of the provided stimulus. Given the repeated high-intensity intermittent nature of team sports match play, including rugby league (Austin et al., 2011; Kempton et al., 2015b; McLellan & Lovell, 2013; Sirotic et al., 2009), it is important to accurately measure the physical output of these demands. As such, HIR distance is often considered an important measure in physical match-play output and commonly reported (McLellan & Lovell, 2013; Sirotic et al., 2009). This measure has been shown to distinguish between elite and sub-elite levels of competition in team sports, while also separating playing positions (Austin & Kelly, 2014; McLellan & Lovell, 2013; Sirotic et al., 2009). Furthermore, it has been revealed that 70% of high-intensity efforts (including HIR) occur prior to pivotal match moments in rugby league, reflecting their importance during match-play (Austin et al., 2011).

In addition to measuring the distance covered at predefined speeds, the assessment of acceleration and deceleration efforts is crucial in quantifying the repeated intermittent efforts performed by players (Gabbett, Jenkins, & Abernethy, 2012; Kempton et al., 2015b; Sirotic et al., 2009). The interaction of the associated metabolic cost of acceleration and velocity has led to a new approach for analysing time-motion data (di Prampero, Fusi, Sepulcri, Morin, Belli, & Antonutto, 2005). Briefly, this method calculates the metabolic cost of accelerations on flat surfaces as equal to the known metabolic cost of incline running (the equivalent angle) at a constant velocity (Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010). Using this acceleration value, an instantaneous energy cost can be estimated, which if multiplied by velocity reveals an individual's metabolic power ($W \cdot kg^{-1}$). This method has been applied to team sports to report the related acceleratory demands of match-play (Coutts, Kempton, Sullivan, Bilsborough, Cordy, & Rampinini, 2015; Furlan, Waldron, Shorter, Gabbett, Mitchell, Fitzgerald, Osborne, & Gray, 2015; Osgnach et al., 2010), however little research exists within rugby league (Delaney, Duthie, Thornton, Scott, Gay, & Dascombe, 2015a; Kempton et al., 2015b). Delaney et al., (2015a) established significant differences between positional groups when examining 1-10 minute windows of acceleratory-running, suggesting the incorporation of acceleration-based methods are necessary in the quantification of running load in rugby league. Likewise, it is reported that when compared to HIR ($>4\ m \cdot s^{-1}$), the distance covered over a pre-defined high power metabolic threshold (HP_{metTh}) was strongly affected by position, with greater acceleration demands exhibited from middle forwards (covering 76% more distance at HP_{metTh} than HIR), compared to outside backs (37%) (Kempton et al., 2015b). However, while these studies outline the inter-positional running and acceleration-based demands, they fail to take into account individual physiological capacities and may misinterpret the relative stress imposed by these efforts.

Despite the propensity to describe physical performance as an index of HIR and high metabolic power, current literature provides little agreeance on the most appropriate thresholds to use. Osgnach and colleagues (2010) suggested the use of an absolute high metabolic power threshold (HP_{metTh}; $> 20\ W \cdot kg^{-1}$), reflecting a power output (W) corresponding to a $\dot{V}O_2$ of ~57 $mL \cdot kg^{-1} \cdot min^{-1}$. However, whilst this may be appropriate for soccer athletes (who are relatively aerobically homogenous), there is great variability in $\dot{V}O_2$ among rugby league and other team sport athletes due to the variability in match-play requirements (Scott et al., 2016c). Similarly, there has been a wide range of speed thresholds used when reporting the locomotive movement demands of team sports, without any physiological justification for their definition. It has been demonstrated that team sports athletes greatly differ in their physiological profile, resulting in varying speeds where high-intensity running begins (Abt & Lovell, 2009). As such, it has recently been suggested that absolute high-intensity speed thresholds should be described as a physical performance speed threshold rather than a high-intensity speed threshold (Abt & Lovell, 2009).

Owing to this, there have been recent efforts to better understand physical demands of sports using relative thresholds. Gabbett (2015) analysed youth rugby league match-play using absolute and relative thresholds, relative to a players' individual peak velocity. This study reported that HIR distance, when expressed in relative thresholds, increased in slower players and decreased in faster players. Further, it has been revealed that distance covered at high-intensity is substantially underestimated when HIR is reported as a function of an individual's second ventilatory threshold (VT_2) (determined from gas-analysis during an incremental treadmill test) compared to absolute thresholds ($> 5.5\ m \cdot s^{-1}$) (Abt & Lovell, 2009). Similarly, Clarke et al., (2015) evaluated utilising VT_2 as a reference speed for HIR in rugby sevens, demonstrating absolute thresholds ($> 5.0\ m \cdot s^{-1}$) may over- or underestimate HIR by up to 14% during match-play. Whilst the proposed VT_2 speed threshold appears an appropriate physiological marker in examining HIR, its application in team sports may be limited due to the impracticality of regular laboratory testing for large squads (Abt & Lovell, 2009). As such, it is important to examine these values using field based test that are easy to implement and have some physiological validity.

Chapter II and IV of the current thesis confirmed past findings, demonstrating the 30-15_{IFT} to be a valid, reliable and sensitive measure of PHIR performance in team sport athletes

(Buchheit, 2008b; Buchheit et al., 2009a; Buchheit et al., 2011b). The $30\text{-}15_{IFT}$ is easily conducted and can test multiple athletes simultaneously, making it appealing for team sports practitioners. Importantly, this test has been shown to relate well to various physiological responses, such as peak oxygen uptake, as well as both the first (VT_1) and second (VT_2) ventilatory thresholds (Buchheit et al., 2009a). Indeed, Buchheit et al., (2009a) revealed that the mean VT_1 and VT_2 corresponded to 68% and 87%, respectively, of V_{IFT}, respectively in team sport athletes. Given these observations, the $30\text{-}15_{IFT}$ may provide a basis on which relative speed thresholds could be established with physiological significance. In addition, it is possible to apply the power associated with VT_2 during the $30\text{-}15_{IFT}$ to individualised high metabolic power thresholds, giving greater insight into the acceleration demands of rugby league match-play. Therefore, the purpose of this study is to identify the differences between relative and absolute (1) speed; and (2) high metabolic power thresholds across rugby league match-play.

METHODS

Design

A longitudinal research design was adopted, where GPS match-play data was collected across a complete National Rugby League competitive season to examine the differences in previously reported absolute speed bands (Sirotic et al., 2009) and metabolic power thresholds (Osgnach et al., 2010), and individualised relative speed and metabolic power zones established via the $30\text{-}15_{IFT}$.

Subjects

Twenty-six professional male rugby league players (n= 26, 26.4 ± 3.7 y, 99.7 ± 8.3 kg) competing in the NRL competition participated in this study. In total, three-hundred and forty-six individual match files were analysed across twenty-two home and away, and three finals matches, across the 2013 NRL season. Players were classified as either outside backs (fullbacks, wingers and centres; n=8, 102 individual files), adjustables (hookers, halfbacks and five-eights; n=6, 77 files), edge-forwards (back-rowers; n=4, 66 files) or middle forwards (props and locks; n=8, 101 files). Interchange players were split into the positional group they participated the majority of the match in. Subjects were informed of the aims and procedures of the study and gave their written informed consent prior to participation. The Institutional Human Ethics Committee approved all experimental procedures (HREC no: H-2013-0283).

Methodology

Match-play data was collected using portable non-differential GPS devices, sampling at 5 Hz and interpolated to 15 Hz (SPI HPU GPSports, Canberra, Australia). The mean (± SD) number of satellites during data collection was 8.9 ± 1.5. For the purpose of validity and reliability, participants were fitted with the same GPS unit each match (Jennings, Cormack, Coutts, Boyd, & Aughey, 2010; Scott et al., 2016b). GPS data was downloaded following the completion of each match using Team AMS (GPSports, Canberra, Australia) and trimmed to include only match time (average match duration was 86 ± 7, 72 ± 18, 72 ± 19 and 41 ± 14 min for outside backs, adjustables, edge forwards and middle forwards, respectively). Once trimmed, each file was exported for analysis with both absolute and relative thresholds applied.

Absolute thresholds were taken from previous research in rugby-league match play (Sirotic et al., 2009) with terminology modified for the purpose of this study. Absolute speed thresholds analysed were: (a) moderate-intensity running (MIR_{Th}; distance at speeds > 3.6 $m \cdot s^{-1}$) and (b) high-intensity running (HIR_{Th}; distance at speeds > 5.2 $m \cdot s^{-1}$). Running volumes over these speed thresholds were directly compared to speeds of the (a) first ventilatory threshold (VT_{1IFT}; distance at speeds > 68% V_{IFT}) and (b) second ventilatory threshold (VT_{2IFT}; distance at speeds > 87% V_{IFT}) (Buchheit et al., 2009a). Distance travelled over a high metabolic power threshold was also analysed, with previously reported methods described by Osgnach (Osgnach et al., 2010) (HP_{metTh}; >20 $W \cdot kg^{-1}$) directly compared to the metabolic power associated with VT_{2IFT} (Equation 6.1) (HP_{metVT2}).

Equation 6.1: $$HP_{metVT2} = EC \times v(VT_{2IFT}) \times GRCF$$

Where EC: energy cost of running at constant speed on flat compact terrain = 3.6 ($J \cdot kg^{-1} \cdot m^{-1}$); vVT_{2IFT}: relative velocity at VT_{2IFT} = 87% V_{IFT}; and GRCF: grass running correction factor =1.29 (Osgnach et al., 2010).

30-15 Intermittent Fitness Test

In order to measure individual's mixed aerobic/anaerobic fitness levels (Scott et al., 2016c) and consequently update relative thresholds throughout the season, participants were required to complete the $30\text{-}15_{IFT}$ at four time points across the season. This testing was interspersed by approximately six weeks. If $30\text{-}15_{IFT}$ performance changed during these time points, subsequent VT_{1IFT}, VT_{2IFT} and HP_{metVT2} thresholds were modified. The intra-individual typical error (TE) across these four testing points was considered low (TE: 0.42 $km \cdot h^{-1}$; CV:

1.9%; unpublished data). The 30-15_{IFT} was performed as previously described by Buchheit (2008b) on a grass field in temperatures between 18-23°C. Players wore their typical training attire and football boots to ensure ecological validity. Nutritional and hydration strategies were implemented as per the club guidelines, with players refraining from undertaking strenuous exercise or taking stimulants for 24 hours prior to testing.

Statistical Analysis

Prior to statistical analyses, assumptions of normality were tested using the Shapiro-Wilk test, and data were log transformed where necessary. The relationship between relative and absolute threshold data was assessed using Pearson correlation coefficients (*r*). The magnitude of *r* was classified as 0.1 – 0.3 small, 0.3 – 0.5 moderate, 0.5 – 0.7 large, 0.7 – 0.9 very large and 0.9 to 0.99 nearly perfect (Hopkins, 2002). Following this, effect sizes (ES) and 90% CI were used to describe the magnitude of difference, interpreted as; ES <0.20 trivial, 0.21 – 0.6 small, 0.61 – 1.2 moderate, 1.21 – 2.0 large and >2.1 very large (Hopkins et al., 2009). Furthermore, the likelihood of the observed effect was established using a progressive magnitude based approach using a customised spreadsheet (Hopkins, 2007), 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 (Hopkins, 2007).

RESULTS

Pearson correlation coefficients (*r*) between distances covered above VT_{1IFT} and MIR (r = 0.94), VT_{2IFT} and HIR (r = 0.94) and HP_{metVT2} and HP_{metTh} (r = 0.93), show a strong positive relationship between absolute and relative measures of running and metabolic loads.

Raw absolute and relative threshold velocities across positional groups are outlined in Table 6.1. Table 6.2 presents the distances covered over absolute and relative speed and metabolic thresholds for these positions.

Table 6.1: Mean velocity (mean ± SD) for relative and absolute speed and metabolic thresholds across positional groups.

Velocity at different thresholds					
Running Threshold	Adjustables	Outside Backs	Edge Forwards	Middle Forwards	Squad
VT_{1IFT} ($m \cdot s^{-1}$)	3.7 ± 0.1	3.6 ± 0.2	3.7 ± 0.1	3.5 ± 0.1	3.6 ± 0.2
MIR_{Th} ($m \cdot s^{-1}$)	3.6	3.6	3.6	3.6	3.6
VT_{2IFT} ($m \cdot s^{-1}$)	4.7 ± 0.2	4.5 ± 0.3	4.7 ± 0.1	4.5 ± 0.1	4.6 ± 0.2
HIR_{Th} ($m \cdot s^{-1}$)	5.2	5.2	5.2	5.2	5.2
HP_{metVT2} ($W \cdot kg^{-1}$)	22.0 ± 0.7	21.1 ± 1.5	21.7 ± 0.5	21.0 ± 0.5	21.4 ± 1.0
HP_{metTh} ($W \cdot kg^{-1}$)	20	20	20	20	20

VT_{1IFT}: First ventilatory threshold (> 68% V_{IFT}), MIR_{Th}: Absolute moderate intensity running threshold (> 3.6 $m \cdot s^{-1}$), VT_{2IFT}: second ventilatory threshold (> 87% V_{IFT}), HIR_{Th}: Absolute high-intensity running distance (> 5.2 $m \cdot s^{-1}$), HP_{metTh}: absolute high metabolic power threshold (>20 $W \cdot kg^{-1}$), HP_{metVT2}: relative high metabolic power threshold (power associated with VT_{2IFT}).

Table 6.2: Distances (mean ± SD) covered across relative and absolute speed and metabolic thresholds across positional groups.

Distance covered above different thresholds					
Running Threshold	Adjustables	Outside Backs	Edge Forwards	Middle Forwards	Squad
VT_{1IFT} (m)	1110 ± 339	1520 ± 211[a]	1301 ± 103	836 ± 184[a]	1192 ± 358
MIR_{Th} (m)	1108 ± 365	1415 ± 208	1319 ± 103	730 ± 176	1133 ± 367
VT_{2IFT} (m)	387 ± 132[b]	809 ± 161[b]	572 ± 76[b]	316 ± 65[b]	526 ± 240
HIR_{Th} (m)	270 ± 83	535 ± 89	413 ± 76	187 ± 35	351 ± 161
HP_{metVT2} (m)	1137 ± 324[c]	1377 ± 189[c]	1296 ± 109[d]	797 ± 175[c]	1144 ± 321
HP_{metTh} (m)	1315 ± 373	1468 ± 216	1486 ± 118	851 ± 204	1264 ± 365

VT_{1IFT}: First ventilatory threshold (> 68% V_{IFT}), MIR_{Th}: Absolute moderate intensity running threshold (> 3.6 $m \cdot s^{-1}$), VT_{2IFT}: second ventilatory threshold (> 87% V_{IFT}), HIR_{Th}: Absolute high-intensity running distance (> 5.2 $m \cdot s^{-1}$), HP_{metTh}: absolute high metabolic power threshold (>20 $W \cdot kg^{-1}$), HP_{metVT2}: relative high metabolic power threshold (power associated with VT_{2IFT}). Positional effect sizes between thresholds: [a] = small effect with MIR_{Th}; [b] = moderate effect with HIR_{Th}; [c] = small effect with HP_{metTh}; [d] = moderate effect with HP_{metTh}

Differences (expressed as effect sizes ± 90% CI) in the distance covered above each of the relative and absolute thresholds for each positional group are displayed in Figure 6.1. Adjustables and edge forwards covered *most likely* same distances above VT_{1IFT} when compared to MIR_{Th} (ES = 0.01; ± 0.20 and ES = 0.05; ± 0.29, respectively). Whilst outside backs and middle forwards completed a *likely* and *very likely* greater volume of VT_{1IFT} when compared to MIR_{Th} (ES = 0.21; ± 0.24 and ES = 0.34; ± 0.23, respectively). Moderate differences were witnessed between VT_{2IFT} and HIR_{Th} for all positional groups. The VT_{2IFT} mean values represent a 146%, 144%, 138% and 167% increase in HIR (compared to HIR_{Th}) across adjustables, outside backs, edge forwards and middle forwards respectively.

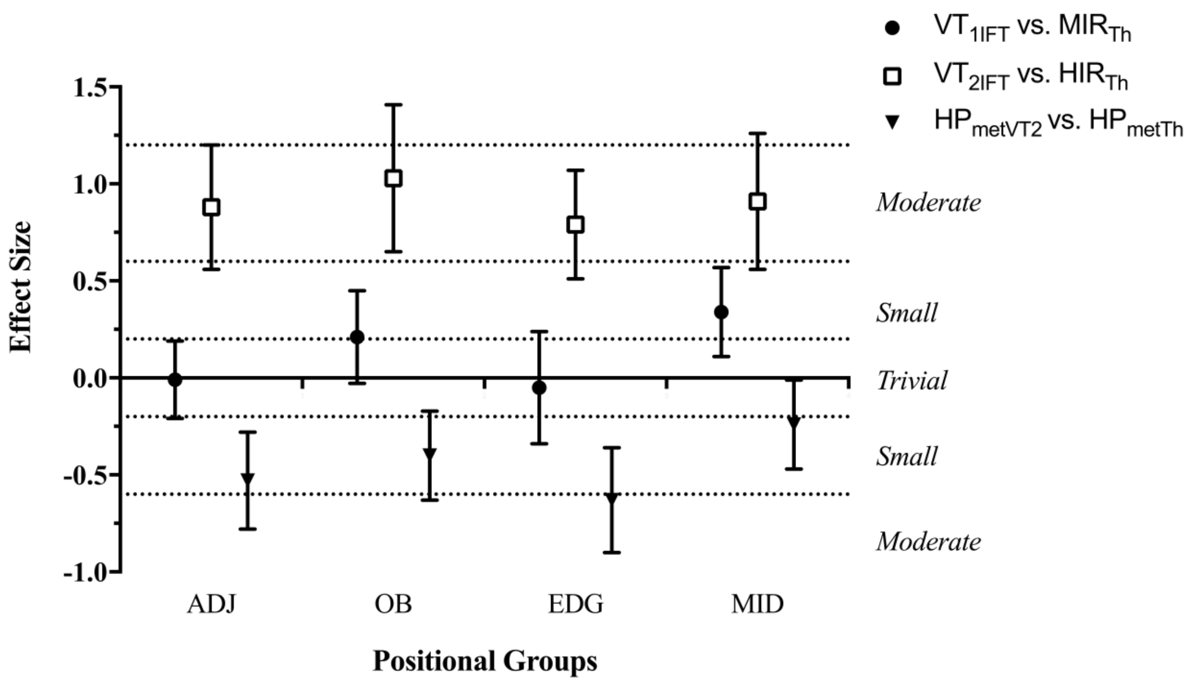

Figure 6.1: Magnitude of differences in running and high metabolic distance between relative and absolute thresholds across positional groups. Values are as standardised effects (effect size ± 90% CI). ADJ: Adjustables; OB: Outside Backs; EDG: Edge Forwards; MID: Middle Forwards.

The relationship between VT_{2IFT} raw velocity and the differences in distance covered above VT_{2IFT} and HIR is presented in Figure 6.2, reflecting a tendency toward players with a lower VT_{2IFT} velocity (and therefore level of fitness) to have a greater underestimation in high-intensity running when using absolute values. Relative high metabolic power thresholds were *likely* to *almost certainly* lower than absolute HP_{metTh} across positions (ES range = 0.24 – 0.63). However, some athletes completed a greater volume of running above HP_{metVT2} when compared to HP_{metTh} depending on the level of fitness of the individual.

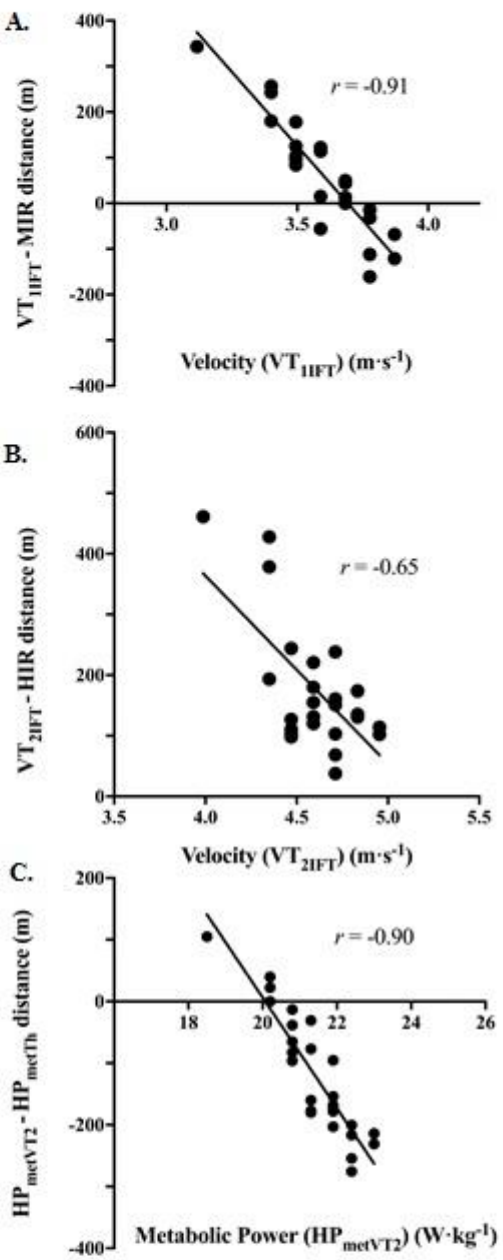

Figure 6.2: A: VT_{1IFT} raw velocity and the differences in distance covered above VT_{1IFT} vs. MIR; B: VT_{2IFT} raw velocity and the differences in distance covered above VT_{2IFT} vs. HIR; C. HP_{metVT2} raw power and the differences in distance covered above HP_{metVT2} and $HP_{metTh.}$

DISCUSSION

The purpose of this study was to identify differences between relative and absolute speed and metabolic power thresholds in quantifying the match-play output of elite rugby league players. The initial finding in the current study demonstrates that whilst strong correlations exist between distances covered at relative and absolute speed thresholds, substantial differences in match-play output were evident when examined across positional groups. This investigation confirmed that HIR should be considered relative to an individual, as the running 'load' of match-play greatly depends on an individual's physical capacities. Similarly, the use of estimated VT_2 as a physiological marker for high metabolic power thresholds may provide a better reference for individual high metabolic running than absolute methods within team sports.

The present findings demonstrate that there is an almost perfect correlation between distance covered above relative and absolute speed thresholds ($r = 0.93 – 0.94$). Additionally, while only small differences existed for distance covered above VT_{1IFT} compared to MIR_{Th}, greater (moderate) differences were observed when comparing distances above VT_{2IFT} with HIR_{Th}. These findings suggest that absolute speed thresholds may underestimate HIR in rugby league match play, particularly for players possessing lower levels of fitness, mirroring results previously reported in soccer (Abt & Lovell, 2009). For example, Abt and Lovell (2009) reported substantially greater distances in HIR (167%) during match-play using VT_2 as their speed threshold, compared to an absolute HIR threshold (> 5.5 $m \cdot s^{-1}$). The importance of HIR and repeated high-intensity efforts in rugby league match-play has previously been outlined (Austin et al., 2011; Austin & Kelly, 2014; Sirotic et al., 2009). Indeed, HIR and repeated high-intensity efforts have been shown to differentiate team success in rugby league (Gabbett & Gahan, 2015; Hulin & Gabbett, 2015), and commonly occur around pivotal match moments

(Austin et al., 2011; Austin & Kelly, 2014). Due to the importance of HIR and repeated high-intensity efforts to performance, there has been an augmented shift to high-intensity interval training to develop these capacities (Buchheit & Laursen, 2013b), however underestimation or misrepresentation of the physical HIR load may lead to poor monitoring and prescription of training load. Further, it has been proposed that an individual's ventilatory threshold (VT_2) provides a more sensitive measure of training-induced changes than typical measures of maximal aerobic capacity (Edwards, Clark, & Macfadyen, 2003; Impellizzeri et al., 2005). Hence, the use of relative thresholds appears desirable for appropriate player monitoring.

The current investigation observed positional differences for distances run above VT_{2IFT} in comparison with distance run above HIR_{Th}. Due to the variations in rugby league positional match-play demands, there is little homogeneity across players' physical, physiological and anthropometrical characteristics (Gabbett et al., 2008a). For instance, a middle forward is required to carry greater body mass and possess explosive qualities to increase their momentum in collisions (Baker & Newton, 2008; Delaney et al., 2015b). In contrast, adjustables are often smaller and require greater PHIR ability due to the increased running demands of their position during match-play (see *Chapter IV*) (Scott et al., 2016c). When examining the differences in distance covered above VT_{2IFT} and HIR_{Th}, all playing positions had an *almost certainly* greater output (ES range = 0.79 – 1.03) when HIR was considered relative to their level of fitness, with the greatest magnitude observed among middle forwards and outside backs. This is reflected in the lower V_{IFT} of middle forwards and outside backs in the current study which mirrors previous findings reported in *Chapter IV* (Scott et al., 2016c). Indeed, *Chapter IV* demonstrated that these two positional groups contribute greater anaerobic qualities during the $30\text{-}15_{IFT}$ to other positions, potentially limiting their performance in this test (Scott et al., 2016c). Due to the heterogeneity in physical characteristics across positions, the relative HIR velocity substantially differs between positions within rugby league. As such, when examining HIR across positions, the use of relative thresholds (e.g. VT_{2IFT}) may provide a better representation of the relative physical HIR load undertaken.

It has been suggested that HIR above VT_2 during match-play does not account for the entire physical running load, as the distance and/or time spent at moderate intensities is not included (Abt & Lovell, 2009). The current findings indicate that absolute MIR thresholds may not only under-estimate the MIR loads in players with lower fitness levels but also over-estimate these loads for players with higher levels of fitness. Adjustables and edge forwards covered substantially less distance above VT_{1IFT} when compared to MIR_{Th}. Conversely, outside backs and middle forwards completed a greater volume of VT_{1IFT} when compared to MIR_{Th}. The small practical differences witnessed in middle forwards and outside backs are likely due to the lower V_{IFT} of these positions, resulting in greater differences between VT_{1IFT} and MIR_{Th} velocities. Further, this study has demonstrated that when applying absolute MIR thresholds, individuals with high levels of fitness may have a tendency to over-estimate the running undertaken above this intensity. Given these findings it appears important that relative speed thresholds also take into account the running load undertaken at moderate intensities as this too is sensitive of individual match play demands.

In addition to speed based thresholds, this investigation examined the differences between high metabolic power thresholds. Importantly, HP_{metVT2} provides an estimated physiological threshold that offers a relative value across individuals with heterogeneous physiological capacities, particularly for those with lower fitness levels. The present findings demonstrate that a strong positive correlation was observed (r = 0.94) between distance run above HP_{metVT2} and $HP_{metTh.}$ Similar to the differences witnessed between running thresholds at moderate intensities, running undertaken above absolute high metabolic power thresholds may under- and over- estimate running load depending on the respective fitness of the individual. The current study showed a main effect in distance travelled above relative and absolute high metabolic power thresholds across positional groups. Edge forwards undertook moderately less distance above HP_{metVT2} when compared to HP_{metTh}, whilst small lower differences were reported across all other positions. Despite adjustables recording a higher relative high metabolic threshold than any other position (22.0 ± 0.7 W·kg^{-1}), only small differences in high metabolic running distances were observed between thresholds. It has been previously demonstrated that edge forwards and adjustables undertake a greater metabolic power output during match play compared to other positions when using HP_{metTh} (Delaney et al., 2015a). As adjustables and edge forwards have higher relative metabolic power thresholds, this may contribute in part to the previously reported greater metabolic power outputs, when using absolute thresholds, than other positions during match-play. Further, whilst it has been demonstrated that HP_{metTh} may over-estimate the high metabolic running load of these positions, it appears edge forwards are most greatly affected. In addition, the current study demonstrates that for players with lower levels of fitness, absolute thresholds may under-estimate this high metabolic running volume. Consequently, the use of estimated VT_2 as an individualised marker for high metabolic power output may provide a better reference for individual high metabolic load within team sports.

Collectively, these findings confirm previous reports in soccer which have shown that the HIR load is under-estimated using current absolute methods, which is directly affected by levels of fitness (Abt & Lovell, 2009). Additionally, the current study demonstrates that the differences between absolute and relative HIR load vary substantially across individuals during match play. It has been suggested that VT_2 is a more appropriate marker to implement as a relative HIR threshold due to its sensitivity in measuring training-induced physiological changes (Abt & Lovell, 2009; Edwards et al., 2003; Impellizzeri et al., 2005). However, given the laboratory nature of incremental treadmill testing to examine ventilatory thresholds, it may be difficult to calculate these physiological functions within large team sport squads. The current study presents the 30-15$_{IFT}$ as a practical field-based test to implement relative thresholds for match demands due to the strong relationship between V_{IFT} and both VT_1 and VT_2 (Buchheit et al., 2009a). Whilst this methodology only provides estimates of these physiological markers, the authors recommend the use of 30-15$_{IFT}$ derived relative thresholds due to the practicality of this measure and its ability to be implemented across large groups. Additionally, it is important to recognise that to increase the accuracy of these thresholds, repeated testing is required across the preparation and competition phase. Whilst the 30-15$_{IFT}$ was performed at four-time points across the competition season to modify relative thresholds, further research should aim at understanding how variable the 30-15$_{IFT}$ is across a competitive phase and whether this was sufficient.

CONCLUSION

The present study demonstrated that considerable differences existed in match-play output across positions when relative thresholds speeds (derived from the 30-15$_{IFT}$) where compared to absolute methods. Similar to previous findings in soccer, it is apparent that the speed at which players begin HIR is dependent on individual capacities and attributes. As such, current absolute methods underestimate the HIR undertaken by rugby league players during match-play. Further, this study found that absolute MIR may not only under-estimate the MIR loads in players with lower fitness levels but also over-estimate these loads for players with higher levels of fitness, confirming the suggestions this needs to be investigated in team sports. Likewise, it is apparent that absolute high metabolic power thresholds may under- and over-estimate this load depending on the respective fitness of the individual, when compared to VT_{2IFT}- based high metabolic power thresholds. Taken together, these findings will impact on the understanding of the HIR running 'load' athletes are exposed to both during training and match-play. Importantly, these findings may have great effect on the periodisation of training, recovery protocols and prescription of high intensity interval training for performance staff.

LIMITATIONS

Whilst this study proposes a novel approach to indivdiualise running thresholds in team sport, it is important to identify that these zones are estimates. As such, drawing conclusions of the physiological cost of running above these thresholds may be inappropriate across populations. Future research should re-asses the running demands of team sport athletes using the physiological suggested derived in a laboratory setting using appropriate protocols.

PRACTICAL APPLICATIONS

- VT_{2IFT} presents a relative HIR threshold that can be applied across a large squad in team sports. It is proposed that this estimated threshold may provide a more practical value than laboratory based VT_2 testing.
- Current absolute HIR thresholds (> 5.5 $m \cdot s^{-1}$) underestimate the physical running load undertaken by the athletes during match-play, therefore VT_{2IFT} may be a greater indicator of this running load, particularly for those with lower fitness levels.
- The relative nature of this 'running load' may provide greater insight into the volume of load performed and consequently be used by performance staff to more precisely prescribe and monitor training sessions and recovery strategies.

Chapter VII

The validity of relative speed thresholds to quantify training in team sports

This chapter is presented as a technical report currently ***in preparation for submission***:

Scott, T. J., and McLaren, S. J. (2018). The validity of relative speed thresholds to quantify training in team sports

Statement of Joint Authorship and Author Contribution

Tannath J. Scott (candidate)

-

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- *Data analysis and interpretation; drafting of technical report*

INTRODUCTION

Training load (TL) encompasses both external and internal dimensions, with external TLs representing the physical work performed during the training session or match and internal TLs being the associated biochemical (physical and physiological) and biomechanical stress responses (Impellizzeri, et al., 2005). The relationships between internal and external loads in team-sport athletes have received much attention to date, with a myriad of studies reporting correlation magnitudes ranging from trivial to very large (Bartlett, O'Connor, Pitchford, Torres-Ronda, & Robertson, 2017; McLaren, Macpherson, Coutts, Hurst, Spears, & Weston, 2018). The dispersion in these effect sizes would suggest that internal-external load relationships are not yet fully understood, which has led some to question the validity of specific external load measures. Greater external loads, particularly those common to the stochastic demands of team-sport training and competition, have been shown to increase metabolic energy costs and soft tissue force an absorption/production (Vanrenterghem, Nedergaard, Robinson, & Drust, 2017), thereby increasing the internal response.

The external TLs are typically measured through global positioning systems (GPS) devices with locomotor demands further analysed using absolute speed thresholds. However, the physiological justification for the definition of these speed thresholds has been recently questioned *(see Chapter VI)*. Indeed, it is suggested that absolute high-intensity speed thresholds should be described as a physical performance speed threshold rather than a high-intensity speed threshold (Abt & Lovell, 2009) and therefore analysed relative to an individual's physical profile. *Chapter VI* proposed the use of relative speed thresholds derived from the 30-15 Intermittent Fitness Test (30-15_{IFT}). This chapter demonstrated differences in running output during match-play when comparing these relative speed thresholds with absolute thresholds commonly reported in rugby league. However, the validity of these 30-

15_{IFT} based speed thresholds are yet to be examined with relation to the internal response derived from training. Therefore, the current technical report aims to assess the construct validity of these speed thresholds examining their relationship with measures of internal TL.

METHODS

Eighteen professional male rugby league players (n= 18, 23.3 ± 3.4 y, 101.5 ± 8.3 kg) competing in the National Rugby League (NRL) competition participated in this study. Training was monitored over a three-week pre-season training period (14.8 ± 0.8 field-based sessions) to examine the relationships between relative locomotor output and measures of internal load. Training data was collected using portable non-differential GPS devices, sampling at 5 Hz and interpolated to 15 Hz (SPI HPU GPSports, Canberra, Australia). The mean (± SD) number of satellites during data collection was 12.4 ± 1.3. For the purpose of validity and reliability, participants were fitted with the same GPS unit each training session (Jennings et al., 2010). The 30-15 Intermittent Fitness Test was undertaken, with the end-stage velocity (V_{IFT}) used to determine relative speed thresholds proposed in *Chapter VI*. The internal TL for each session was calculated using the sRPE method (Foster et al., 2001) for each player during the study period. This method involved multiplying the training duration in minutes by the mean training intensity (measured using Borg CR10 scale). The HR-based training impulse (TRIMP) method proposed by Edwards (1993) and time ≥90% HR_{max} were also used as a criterion measure of internal TL in the present study.

A within-player design was used to determine if higher session distances covered above the V_{IFT} based thresholds were associated with higher session internal loads. This is the appropriate method as it permits the analysis of within-subject changes by removing between-subject differences (Bland & Altman, 1995). Confidence limits (CL; 90%) for the within-player correlations were calculated as per Altman and Bland (2011). The following scale of magnitudes was used to interpret the magnitude of the correlation coefficients: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; >0.9, nearly perfect (Hopkins et al., 2009). Correlations were evaluated mechanistically and only deemed clear if the 90% CL did not overlap substantially positive and negative effect thresholds by a likelihood of ≥ 5% (Batterham & Hopkins, 2006). Otherwise, the chances of the true (population) correlation being at least that of the observed magnitude was interpreted using the following scale of probabilistic terms: 5–24.9%, possibly; 75–94.9%, likely; 95–99.4%, very likely; ≥ 99.5%, most likely (Batterham & Hopkins, 2006).

RESULTS

Results are displayed in table 7.1 below.

Table 7.1: Within-athlete relationships between session distances covered above V_{IFT}-derived speed thresholds and session internal loads during a three-week pre-season training block in elite rugby league players.

Distance covered above relative threshold	**Relationship (*r*; ±90% CL) with measures of internal load**		
	sRPE-TL	TRIMP	Time ≥90% HR_{max}
>68% V_{IFT}	0.60; ±0.07 *very likely* large	0.51; ±0.08 *possibly* large	0.62; ±0.07 *most likely* large
>87% V_{IFT}	0.51; ±0.08 *possibly* large	0.45; ±0.09 *most likely* moderate	0.56; ±0.08 *likely* large
>100% V_{IFT}	0.36; ±0.09 *likely* moderate	0.37; ±0.10 *likely* moderate	0.44; ±0.09. *very likely* moderate

CL: confidence limits; HR_{max}, maximum heart rate; *r*, Pearson's product moment correlation coefficient; sRPE-TL, session rating of perceived exertion training load; TRIMP, Edwards heart-rate-derived training impulse, V_{IFT}, end-stage velocity during the 30–15 Intermittent Fitness Test.

DISCUSSION

Associations between external and internal measures of TL and intensity are important in understanding the dose–response nature of team-sport training and competition. These relationships may also provide evidence for the validity of relative external TL measures. The current study found moderate to large relationships exist between relative locomotor output (using V_{IFT} derived thresholds) and internal measures of TL, demonstrating the validity of this method to quantify running demands in rugby league. Importantly, establishing the construct validity of relative speed thresholds may be an integral aspect of athlete monitoring in team sports that include athletes with heterogenous physical qualities (*see Chapter VI)*. The current findings demonstrate a stronger association between relative locomotor demands at lower intensities and measures of internal load. These results are in support of past findings that have reported on the relationship between internal TL and absolute external TL measures, observing weaker correlations between these measures at higher velocities (McLaren et al., 2018).

It is theorised that centrally-derived physiological responses may have a greater influence on our perception of effort, and may give reason for the poor linear relationship between running velocity and internal training response (Vanrenterghem et al., 2017). Given the ability to sustain muscle contractions during locomotion is largely dependent on the cumulative provision of substrate and oxygen to the peripheral systems, this association seems logical. Indeed, an individual's perception of effort is believed to be largely driven by the neuronal process experienced from central motor commands to the lower-limb and respiratory muscles during locomotion (Marcora, 2009). As such, it appears sensical that the distance of running covered above a lower-intensity threshold would see greater relationships with perceived exertion and other measures of internal TL (i.e. heart rate response) than that undertaken over higher velocities (McLaren et al., 2018).

Lastly, the strength of these correlations is substantial evidence to suggest these relative thresholds valid in the quantification of external TL. Whilst there is an imperfect association between the external loads assessed and measures of internal load, this is unsurprising. The observed moderate to large relationships between measures of relative external and internal TL is likely due to the myriad of non-load-related factors that influence an individual's perceived exertion and internal response during exercise (Robertson & Noble, 1997). Taken together, these findings establish the construct validity of V_{IFT} derived speed thresholds to evaluate relative external TLs and further our understanding of the dose–response nature of team-sport training.

Chapter VIII

Acute metabolic, cardiorespiratory and neuromuscular effects of high-intensity interval training in rugby league players

Statement of Joint Authorship and Author Contribution

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ABSTRACT

This study examined the acute metabolic, cardiorespiratory and neuromuscular effects of differently structured high-intensity interval training (HIT) and tactical training sessions, as well as changes following a pre-season training period. Thirty-one junior-elite Australian rugby league players completed four × 4 min HIT exercises typical of team sport athletes with a 2 min passive recovery in between exercises. Exercise intensity was prescribed relative to 30-15$_{IFT}$ performance conducted prior to each testing period, ranging from 85 – 105% V_{IFT}, with manipulations made to shuttle length, work: rest ratios, recovery modalities (active and passive) to alter the physiological response of each HIT exercise. Blood lactate ($[La^{-}]_b$), counter-movement jumps (CMJ) and rating of perceived exertion (RPE) were recorded following HIT exercises (within 60 s of completion), while time spent above 90% heart rate maximum (HR_{90}) was calculated. The order of HIT exercises where randomised over three protocols undertaken two days apart to assess the influence on exercise arrangement. Each protocol was re-tested following a six-week training period. Effect sizes (ES) quantified between-condition differences. Substantial increases in $[La^{-}]_b$ occurred following the second 4 min exercise bout (ES range = 0.94 – 1.18). No differences were witnessed following each protocol in $[La^{-}]_b$ or RPE, despite some substantial differences witnessed in HR_{90} between each protocol at the conclusion. The 4 min HIT exercise incorporating active recovery had the greatest effect on (ES range = 0.06 – 0.88). Following the training period, $[La^{-}]_b$ (protocol one; ES= 0.68 ± 0.31; ES ± CI) and HR_{90} (protocol one; ES = 0.75; ±0.37 and two: ES = 0.40; ±0.29) reposes were substantially lower. CMJ power outputs showed no substantial changes across any condition. These findings demonstrate that the arrangement of HIT exercises can influence the physiological responses of a training session. The accumulation of $[La^{-}]_b$ may be more sensitive to HIT incorporating active recoveries rather than HIT with greater mechanical (acceleration and deceleration) loads.

Keywords:

training prescription, conditioning, 30-15 Intermittent Fitness Test, team sports

INTRODUCTION

Team sport match-play is characterised by repeated high-intensity movements interspersed with periods of low-intensity activity, requiring physical efforts derived from both aerobic and anaerobic sources (Bangsbo, 2000a; Bangsbo et al., 2007; Bangsbo et al., 2006). Aerobic fitness has been shown to be a determinant in the performance of team sports, especially in the ability to finish a match (Kempton et al., 2015a; Mohr et al., 2003), to cover distance (Rampinini et al., 2007b), to repeat and recover from high-intensities efforts (Bishop & Spencer, 2004; Dupont et al., 2010b), and to reduce the deterioration in some technical skills (Rampinini et al., 2009). Further, high-intensity efforts typically occur at decisive moments of match-play (Austin et al., 2011) and may differentiate successful and non-successful teams (Gabbett & Gahan, 2015). As a result, coaches must appropriately develop these aerobic and repeated high-intensity capacities to adequately prepare athletes for match-play demands.

High-intensity interval training is a time efficient method to progressively overload the cardiopulmonary, metabolic and neuromuscular/musculoskeletal systems (Buchheit, 2012; Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b). Briefly, HIT incorporates either repeated short (<45 s) or longer (2-4 min) bouts of high-intensity exercise, interspersed with active or passive recovery periods (Buchheit & Laursen, 2013a). Alongside other methods of conditioning (e.g., small sided games), the appropriate prescription and continual progression of HIT has been shown to enhance an athlete's physiological capacities (Wong, Chaouachi, Chamari, Dellal, & Wisloff, 2010). More specifically, the implementation of HIT may lead to rapid improvement in aerobic and repeated high-intensity running capacities (Wong et al., 2010). High intensity interval training is commonly viewed as an effective method to maximise physiological adaptations during physical preparation phases, with the aim to improve the outcome of physical output during match-play. However during this preparatory phase, the organisation and outcome of these sessions may be compromised due to concurrent tactical and physical training sessions. For example, residual neuromuscular fatigue post-HIT may inhibit the rate of force development during succeeding training sessions, potentially compromising planned neuromuscular loadings (Blazevich, 2012). As such, it is integral when integrating HIT with tactical, speed, agility and strength sessions that practitioners understand the cardiopulmonary, metabolic, and neuromuscular fatigue/stress imposed to subsequently appropriately periodise this training.

Currently there is a paucity of research revealing the impact of consecutive HIT exercises within a training session. This is important as seldom do HIT sessions only incorporate one drill repeated over multiple sets. Indeed, it is more typical for practitioners to manipulate work and rest intensities and recovery periods within drills across a training session to stress different physiological systems. Despite this, the majority of studies have aimed to examine the physiological responses to independent HIT strategies, such as assessing the influence of work: rest intervals, work intensity and recovery modality (Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b). For example, it has been found that there is an increased anaerobic glycolytic contribution due to greater peripheral metabolic disturbance when intermittent exercise at the same intensity was performed in shuttle format compared with traditional in-line running (Dellal, Keller, Carling, Chaouachi, Wong del, & Chamari, 2010). Also, introducing an active recovery between HIT efforts induced a faster decline in oxyhemoglobin (Dupont, Moalla, Guinhouya, Ahmaidi, & Berthoin, 2004b). While we currently have a reasonable understanding of the metabolic and neuromuscular fatigue/load from these individual HIT exercises, it is not known how these physiological responses are effected by preceding and/or succeeding HIT exercises with varying metabolic and neuromuscular aims. Additionally, the fatigue/load related to these sessions may be compromised and altered during preparatory periods when tactical, agility, speed or strength session are performed in the hours prior to HIT. Indeed, while eight weeks of concurrent HIT, strength and tactical training has shown improvement in explosive performances (vertical jump height, 10-m and 30-m sprint times) and aerobic fitness in soccer players (Wong et al., 2010), it is not known what influence these concurrent sessions have on physiological responses when performed prior to HIT. Furthermore, while improvements in absolute aerobic fitness may be achieved during this period of concurrent training, it is unknown whether this adaptation may also improve physiological functioning at a relative running intensity rather than increasing peak fitness.

The current study aims to (1) identify the metabolic and neuromuscular effects of different exercise arrangements within an HIT session; (2) investigate how team sport athletes respond to the same session following a six-week training period and (3) examine how these responses are influenced by tactical/ technical sessions undertaken immediately before HIT.

Methods

Participants

Thirty-one junior-elite rugby league players (19.2 ± 0.6 y, 93.6 kg ± 10.4 kg, Σ7 skinfolds: 78.4 ± 25.4 mm) competing in the Australian National Youth Competition (NYC; Under 20’s) participated in this study. All participants underwent medical screening and did not present any contraindications for vigorous exercise. Participants were informed of the experimental procedures, risks and/or benefits involved and provided written consent and parental/guardian consent prior to participation. Experimental procedures were approved by the Institutional Human Ethics Committee (HREC no: H-2013-0283).

Experimental procedures

To limit the circadian effect on performance as well as to reduce the effect of external factors (such as temperature), all testing procedures were performed during regular training times. The first testing period was performed following two weeks of pre-conditioning to ensure players were physically capable to undertaking the HIT protocols. To standardise athlete nutritional substrate status prior to all testing periods the team dietician provided nutritional and hydration strategies to all players as per club guidelines. In order to ensure sufficient carbohydrate intake during the testing period, nutritional records were taken as was typical of club player monitoring policy. Athletes were also required to consume identical mixed diets (i.e., no CHO-loading) for 24 h before each experimental trial. To examine the influence of separate HIT drills within a training session, four 4 min HIT exercises were conducted in different orders across three separate sessions with 2 min passive recovery in-between each exercise (described below). Capillary blood samples were collected following each exercise in protocol one and three and at the halfway (following exercise two) and completion of protocol two, within 30-60 seconds from the cessation of exercise, from a hyperaemic fingertip for the analysis of blood lactate ($[La^-]_b$) concentration using a lactate Scout (EKF-Diagnostic, Berlin, Germany). Likewise, within 30-60s of completing the exercise drill athletes performed three counter-movement jumps (CMJ), measured using a linear position transducer (LPT; GymAware optical encoder; Kinetic, Canberra, ACT) attached to a broomstick which sat across the athletes' shoulders, with their best result (considered peak jump height) analysed for peak concentric force and peak velocity. The use of an LPT to quantify power and velocity during this movement has been shown to demonstrate moderate levels of reliability (9.3 – 12.2% CV), despite the observed decrease in the validity of mechanical measurements as velocity increases (Giroux, Rabita, Chollett, & Guilhem, 2015). However, it is suggested that the variability of measurements performed during high-velocity jumps cannot be attributed to devices limitations

(Jidovtseff, Crielaard, Cauchy, & Croisier, 2008) and therefore when examining velocity and power based measures in the field, LPT may be an appropriate method. Players undertook the testing protocols in a staggered rotation to ensure there was no delay when performing CMJ and to standardise the time between $[La^{-}]_b$ collection and the completion of the recent HIT drill. To understand the implications of tactical/technical sessions on ensuing HIT more thoroughly, groups were divided with one group (n=15) completing a standardised skill session prior to HIT and one group following (n=16).

30-15 Intermittent Fitness Test

Players were required to complete the $30\text{-}15_{IFT}$ prior to both training interventions to prescribe relative distances for individual HIT protocols, and were asked to refrain from undertaking any strenuous exercise in the 24-hour period prior to testing. Players underwent a familiarisation session one week prior to testing, with coaching staff providing procedural advice when necessary. Briefly, the $30\text{–}15_{IFT}$ consisted of 30-second shuttle (40-m) runs interspersed with 15-second passive recovery periods. The initial running velocity was set at 8 $km{\cdot}h^{-1}$ for the first 30-second stage, and speed was increased by 0.5 $km{\cdot}h^{-1}$ every 30-second stage thereafter. To assist athletes in regulating their running speed a short beep sounded as they were to be in the 3-m zones either at each end of the running area, or the mid-line (20-m line). If players were unable to reach the 3-m zone on 3 consecutive occasions, scores were recorded as the last stage completed successfully (V_{IFT}) (Buchheit, 2008b). This test has been demonstrated to be valid (Buchheit, 2008b; Covic et al., 2016; Scott et al., 2016c) and reliable among team sport athletes, with a TE of 0.36 $km{\cdot}h^{-1}$ (CV 1.9%) reported in a similar cohort of athletes (Scott et al., 2015).

Physical Training

Following the first HIT testing period, players took part in six weeks of normal team training, which was prescribed by performance staff and tactical coaches. Training was not modified or altered in any way for the purposes of this study, with no influence or obstruction given to staff or players. Across the six-week training period players undertook 24 scheduled on-field training sessions. Each week was comprised of two conditioning sessions, four skills sessions and a speed and agility session across four training days (see Table 8.1). After this training block, players undertook the same HIT testing layout.

Table 8.1: Training events (commencement time) [mean individual session training load ± SD; determined from the sRPE method] completed by rugby league players during the six-week training period (pre-season).

Monday (PM)	Tuesday (PM)	Wednesday	Thursday (PM)	Friday	Saturday (AM)	Sunday
Speed/ Skills Training (1630 h) [468 ± 92 AU]	*Conditioning/ Skills Training* (1630 h) [639 ± 136]		*Agility/ Skills Training* (1630 h) [440 ± 82 AU]		*Conditioning/ Skills Training* (0700 h) [605 ± 119 AU]	
	Strength Training (1800 h) [280 ± 59 AU]		*Strength Training* (1800 h) [379 ± 67 AU]		*Strength Training* (0930 h) [341 ± 79 AU]	

AU = arbitrary units

High-Intensity Training Protocols

The HIT protocol prescribed was designed to elicit differing physiological responses (with varied metabolic and neuromuscular emphasises), with all exercises typical of that prescribed for team sports (Table 8.2). To assess the effect of exercise order, each HIT exercise rotated in differing drill orders, which formed protocol one, two and three. The outline of these protocols can be viewed in Table 8.3. These protocols where performed two days apart with a recovery day scheduled in-between (Figure 8.1). To standardise the relative physiological response to this training stimulus, all HIT methods were prescribed from V_{IFT} obtained from the 30-15$_{IFT}$ prior to the respective testing block.

Table 8.2: Outline of high-intensity running exercises.

Exercise	Reps	Work: Rest	V_{IFT} (%)	Recovery (%)	Shuttle Length
$SHTL_{30}$	4	30:30 s	90	Passive	30
$SHTL_{15}$	4	30:30 s	85	Passive	15
SL_{ACTREC}	8	15:15 s	85	60	Straight line
$SHTL_{30HI}$	8	15:15 s	105	Passive	30

$SHTL_{30}$: 30 m shuttle length as described in the table; $SHTL_{15}$: 15 m shuttle length as described in the table; $SL_{ACTREC:}$ Straight line active recovery based drill as described in the table; SHTLE30HI: 30 m shuttle length at an intensity greater than SHTL30 as describe above in the table; VIFT: final velocity at termination of the 30-15 Intermittent Fitness Test.

Table 8.3: Outline of each high-intensity interval training protocol.

Protocol	Drill 1	Drill 2	Drill 3	Drill 4
1	$SHTL_{30}$	$SHTL_{15}$	SL_{ACTREC}	$SHTL_{30HI}$
2	$SHTL_{30HI}$	SL_{ACTREC}	$SHTL_{15}$	$SHTL_{30}$
3	$SHTL_{15}$	$SHTL_{30HI}$	$SHTL_{30}$	SL_{ACTREC}

$SHTL_{30}$: 30 m shuttle length as described in the table; $SHTL_{15}$: 15 m shuttle length as described in the table; $SL_{ACTREC:}$ Straight line active recovery based drill as described in the table; SHTLE30HI: 30 m shuttle length at an intensity greater than SHTL30 as describe above in the table.

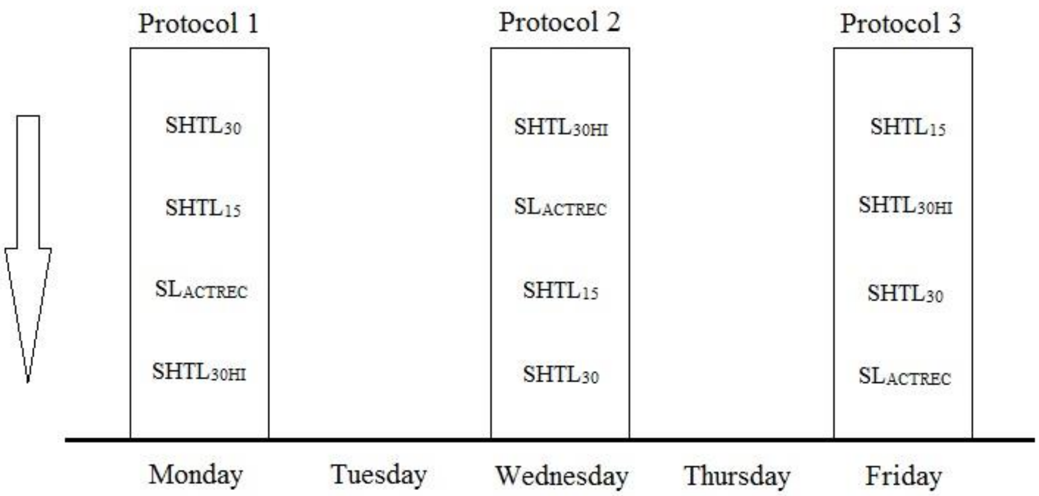

Figure 8.1: A schematic depiction of the study protocols and high-intensity interval training exercises within each protocol (ordered from top to bottom).

Training Load Variables

External loads were measured using portable non-differential GPS devices, sampling at 5Hz and interpolated to 15 Hz (SPI HPU GPSports, Canberra, Australia). The mean (± SD) number of satellites and HDOP during the data collection periods was 11.8 ± 2.7 and 1.1 ± 0.1, respectively. For the purpose of reliability, participants were fitted with the same GPS unit each training session (Scott et al., 2016b). GPS data was downloaded and trimmed using Team AMS (GPSports, Canberra, Australia) and exported for analysis. External measurements collected for analysis included measures validated in *Chapter VI* as well as total distance. Relative high-intensity running and high metabolic load were calculated from estimated second ventilatory speed thresholds based on the $30\text{-}15_{IFT}$ as per *Chapter VI*. Due to the reported poor inter-unit reliability of GPS for measuring acceleration (Buchheit et al., 2014), the current study calculated the average acceleration/deceleration (Ave Acc/Dec; $m \cdot s^{-2}$) of each exercise as described previously (Delaney, Cummins, Thornton, & Duthie, 2017). Briefly, this technique utilised customised software (R, v R-3.1.3.) to examine the raw GPS movement data (sampled at 5 Hz), taking the absolute value of all acceleration/deceleration data, and averaging over the duration of the defined period. This method has been demonstrated to have good to moderate levels of reliability (1.2 – 5.7% CV) (Delaney et al., 2017). Internal TL was calculated using the sRPE method (Foster et al., 2001) for each player across the study period. In addition, during the testing protocols, training intensity was measured using the CR10 scale, collected following each exercise and at the conclusion of the HIT protocol. Heart rate was recorded throughout each training session at one second intervals using a Polar T^2 system using R-R recording monitors (Polar Electro, Kempele, Finland), with average HR and time spent above 90% maximal HR (determined as peak HR achieved during the $30\text{-}15_{IFT}$; $HR_{>90}$) calculated for analysis with each exercise.

Statistical Analysis

Prior to statistical analyses, assumptions of normality were confirmed**.** Differences in metabolic and neuromuscular responses between each exercise, and separately between each protocol were examined using linear mixed models. In these models, individual athletes were included as a random effect. The least squares mean test provided pairwise comparisons between responses between each exercise and protocol, where differences were described using standardised effect sizes (ES) and 90% confidence intervals (CI), categorised using the thresholds of <0.2 trivial, 0.21 – 0.60 small, 0.61 – 1.20 moderate, 1.21 – 2.0 large and >2.0 very large (Hopkins et al., 2009). The likelihood of the observed effect was established using a progressive magnitude-based approach, differences were considered substantial when the likelihood that the true value was greater than the smallest worthwhile difference (SWD; 0.2 × the between -subject SD) exceeded 75% (Batterham & Hopkins, 2006). All statistical analyses were conducted using R Studio statistical software (V 0.99.446).

RESULTS

A summary of the metabolic and neuromuscular responses, and internal/external loads to each drill and protocol are described in Table 8.4.

Table 8.4: Raw data collected across all variables over each high-intensity interval training protocol (mean ± SD).

Protocol	Exercise	Blood Lactate (mM)	RPE (AU)	HR_{Avg} (b·min^{-1})	$HR_{>90}$ (min)	Distance (m)	HIR (VT_{2IFT}) (m)	HML (m)	Ave Acc/Dec (m·s^{-2})	Peak Concentric Power (W)
One	$SHTL_{30}$	7.1 ± 2.5	6.0 ± 1.4	167 ± 13	1.20 ± 1.13	569 ± 45	296 ± 48	335 ± 25	2.8 ± 0.3	7208 ± 2243
	$SHTL_{15}$	8.0 ± 2.6	7.2 ± 1.2	176 ± 14	2.24 ± 1.08	481 ± 23	49 ± 30	232 ± 21	3.4 ± 0.2	7404 ± 2019
	SL_{ACTREC}	11.1 ± 2.7	8.5 ± 0.9	185 ± 8	3.33 ± 0.50	916 ± 73	186 ± 107	224 ± 82	2.4 ± 0.3	6951 ± 1376
	$SHTL_{30HI}$	10.5 ± 2.4	8.9 ± 0.9	183 ± 9	3.08 ± 0.49	608 ± 38	155 ± 81	293 ± 60	3.2 ± 0.3	7486 ± 2483
Two	$SHTL_{30HI}$		7.1 ± 1.3	166 ± 12	1.64 ± 1.10	616 ± 38	323 ± 48	382 ± 29	3.4 ± 0.2	7240 ± 1722
	SL_{ACTREC}	9.8 ± 2.4	7.9 ± 1.0	183 ± 14	3.19 ± 0.56	925 ± 49	229 ± 108	253 ± 84	2.4 ± 0.3	7433 ± 2245
	$SHTL_{15}$		7.9 ± 1.0	176 ± 11	2.16 ± 1.08	483 ± 69	33 ± 44	208 ± 28	3.4 ± 0.2	7631 ± 2408
	$SHTL_{30}$	10.7 ± 2.3	8.4 ± 1.1	176 ± 11	2.49 ± 0.86	554 ± 45	224 ± 72	294 ± 46	2.7 ± 0.3	7787 ± 2211
Three	$SHTL_{15}$	6.2 ± 1.6	6.3 ± 1.0	165 ± 12	0.99 ± 0.98	472 ± 19	56 ± 39	232 ± 15	3.4 ± 02	7337 ± 2071
	$SHTL_{30HI}$	8.3 ± 1.9	8.1 ± 0.8	177 ± 11	2.60 ± 0.77	623 ± 41	265 ± 82	354 ± 40	3.3 ± 0.3	7309 ± 1664
	$SHTL_{30}$	9.4 ± 2.3	8.2 ± 0.7	177 ± 10	2.40 ± 0.96	561 ± 42	193 ± 70	281 ± 30	2.8 ± 0.3	7695 ± 1959
	SL_{ACTREC}	10.1 ± 2.2	9.0 ± 0.7	181 ± 11	3.15 ± 0.55	913 ± 76	182 ± 108	215 ± 87	2.4 ± 0.3	7853 ± 1916

RPE: Rating of perceived exertion, determined by Borg CR10 scale; HR_{Avg}: Heart rate average across each 4 minute exercise; $HR_{>90}$: Time above HR>90% maximal heart rate; HIR: High-intensity running; VT_{2IFT}: running distance above second ventilatory threshold (> 87% V_{IFT}), HML: metabolic power threshold (power associated with VT_{2IFT}).

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Figure 8.2 provides a graphical display of the raw metabolic and neuromuscular responses for each exercise for each protocol, listing substantial differences for each exercise between protocols. Differences between protocols for each variable are shown in Figure 8.3.

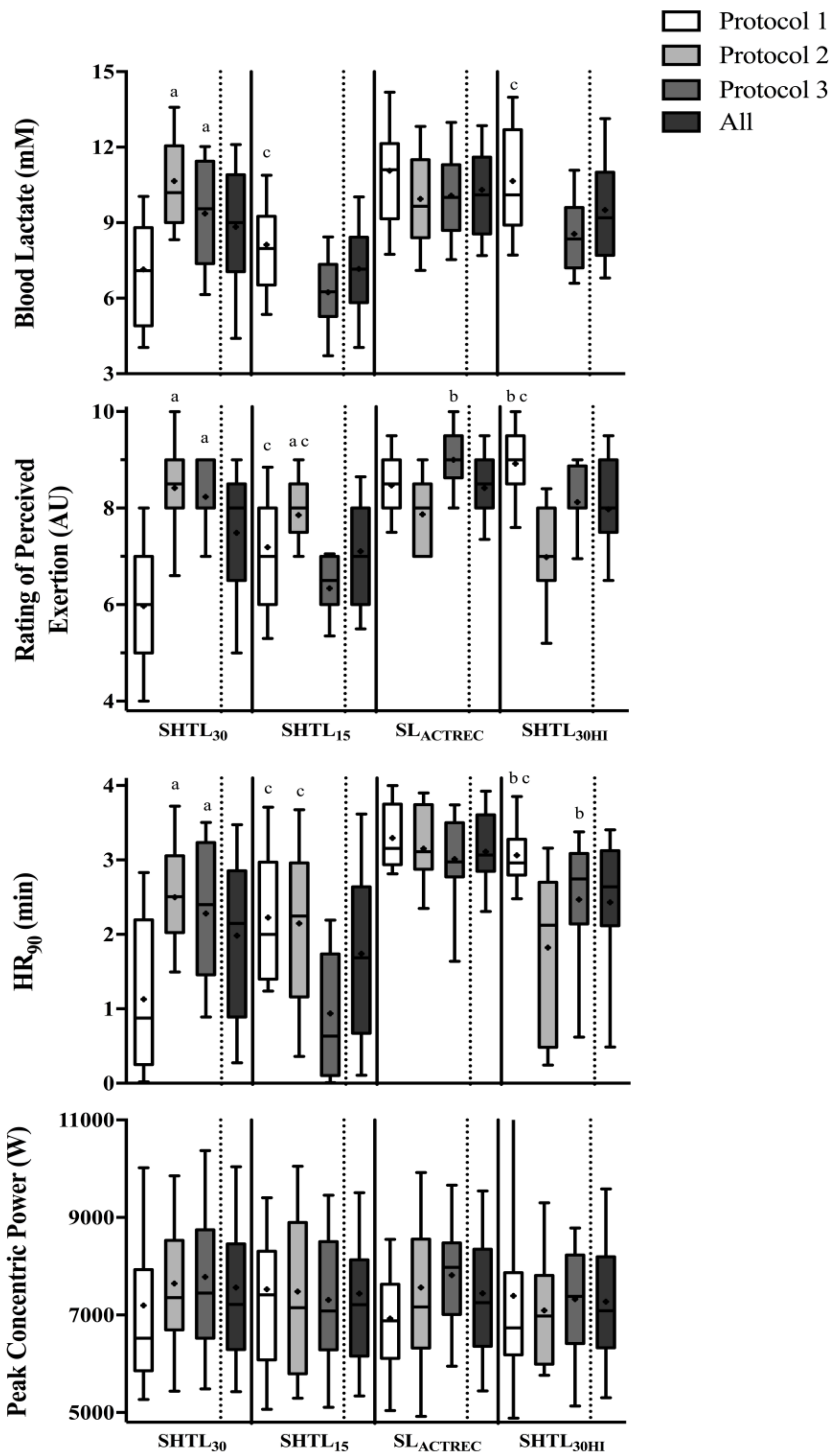

Figure 8.2: Box plots of metabolic and neuromuscular responses for each exercise over protocol one, two, three and all data. Solid line is median, + represents the mean. Whiskers above and below the box indicate the 90th and 10th percentiles. $HR_{>90}$: Time above HR>90% maximal heart rate. [a] Substantially greater than the same exercise in protocol 1; [b] Substantially greater than the same exercise in protocol 2; [c] Substantially greater than the same exercise in protocol 3.

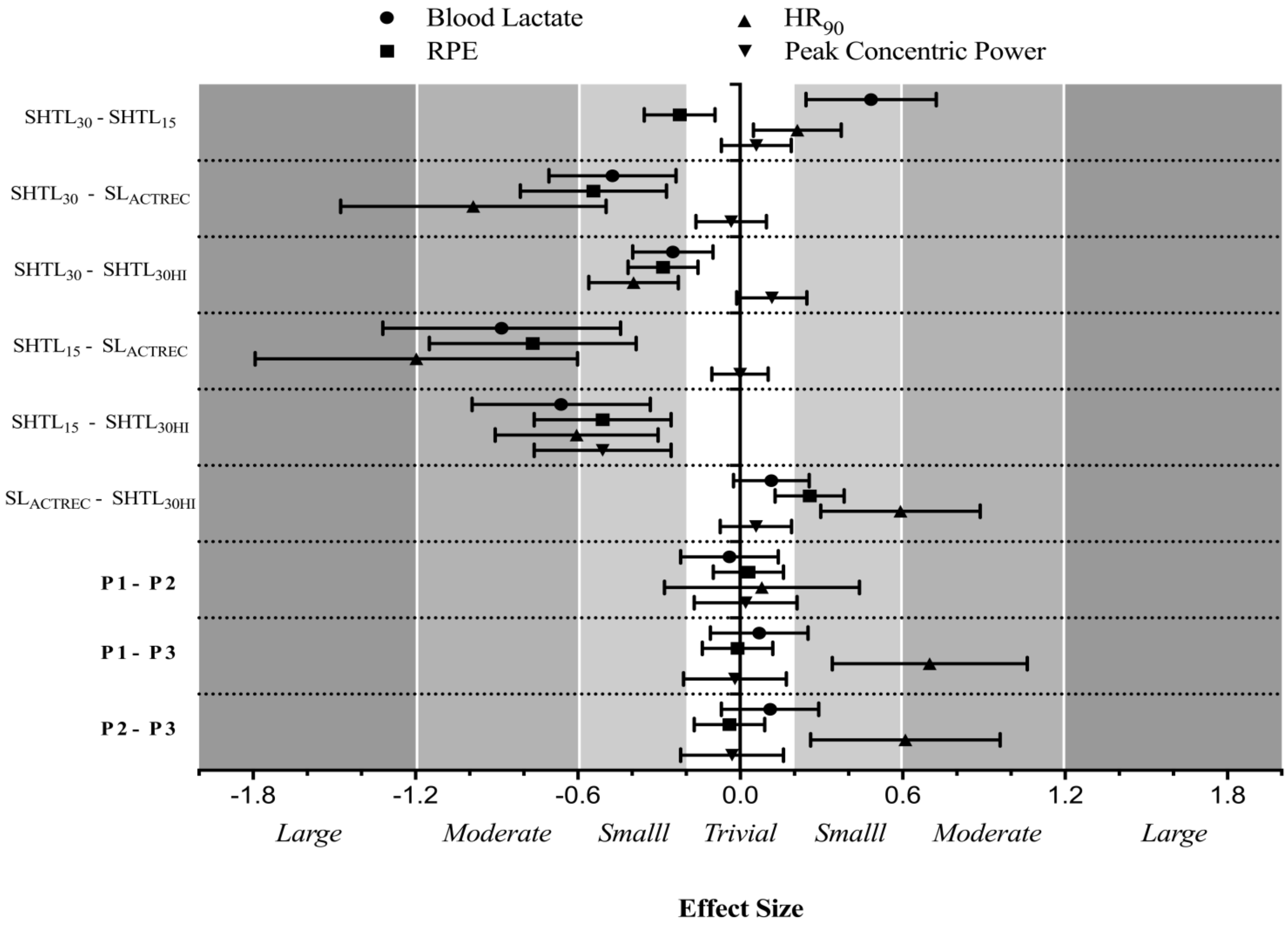

Figure 8.3: Magnitude of differences in metabolic, cardiorespiratory and neuromuscular responses between HIT exercises and between protocols. Values are as standardised effects (effect size ± 90% CI). P1: Protocol 1; P2: Protocol 2; P3: Protocol 3. HR_{90}: Time above HR>90% maximal heart rate; RPE: Rating of Perceived Exertion.

As presented in Figure 8.3, accumulated HR_{90} was higher in protocol one and two when compared with protocol three (ES = 0.70; ±0.36 and ES = 0.61; ±0.35, respectively). When comparing exercises, $[La^{-}]_b$ was moderately lower following $SHTL_{15}$ when compared to SL_{ACTREC} and $SHTL_{30HI}$ (ES = 0.88; ±0.44 and ES = 0.66; ±0.33, respectively). SL_{ACTREC} had moderately and largely higher HR_{90} than $SHTL_{30}$ and $SHTL_{15}$ (ES = 0.99; ±0.49 and ES = 1.20; ±0.60, respectively), while $SHTL_{30HI}$ was moderately greater than $SHTL_{15}$ (ES = 0.60; ±0.30,). SL_{ACTREC} reported substantially higher RPE than $SHTL_{15}$ (ES = 0.77; ±0.38).

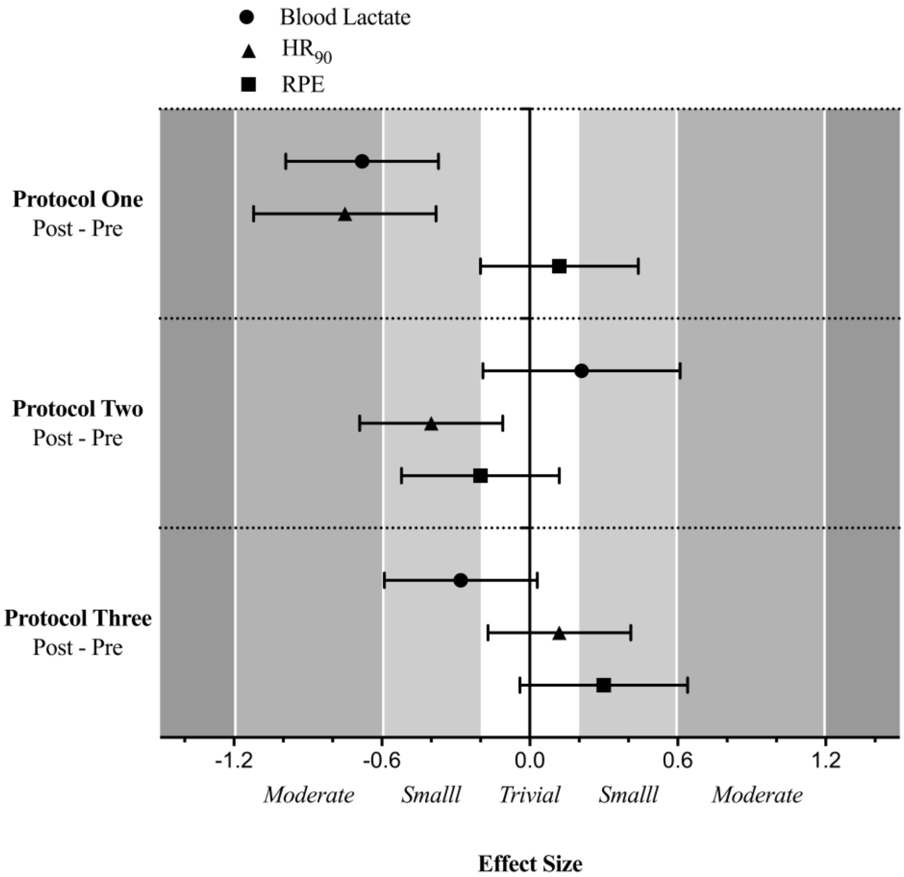

Figure 8.4: Magnitude of differences in metabolic, cardiorespiratory and neuromuscular responses for each protocol between post and pre- training period. Values are as standardised effects (effect size ± 90% CI). HR_{90}: Time above HR>90% maximal heart rate; RPE: Rating of Perceived Exertion.

Figure 8.4 above displays $[La^{-}]_b$ and HR_{90} responses pre- and post- the six-week training period. Blood lactate responses were moderately lower post- training period following protocol one (ES = 0.68; ±0.31). Accumulated HR_{90} was moderately lower post- training period at the completion of protocol one (ES = 0.75; ±0.37) and moderately lower following protocol two (ES = 0.40; ±0.29). Only trivial differences were observed in RPE, peak concentric power and peak velocity for each protocol when comparing pre- and post- training period. No substantial differences were reported for any GPS variable between protocols. When comparing GPS variables between the post- and pre- training periods, total distance and Ave Acc/Dec observed a *likely* small increase (ES = 0.42; ±0.34 and ES = 0.34; ±0.29, respectively), Unclear differences were observed in relative HIR and HML distances across these periods.

The tactical skills session undertaken by the training group conducted prior to each HIT protocol was considered 'somewhat hard' (RPE = 4.2 ± 1.1 AU; sRPE = 131 ± 28). No substantial differences in any measure was recorded during or at the conclusion of any protocol between the training groups (ES range = 0.06 – 0.14).

DISCUSSION

The primary aim of the study was to identify the acute metabolic, cardiorespiratory and neuromuscular effects of team sport-based HIT drills during various arrangements of a typical conditioning session. The current study observed that $[La^{-}]_b$ and RPE responses differed across each protocol despite no substantial differences at the conclusion of each protocol. A secondary finding was whilst no differences in $[La^{-}]_b$ and RPE were observed, accumulated HR_{90} was substantially greater in the first and second protocol in comparison to the protocol three. Despite these acute metabolic and cardiorespiratory responses, the current study observed little display of acute neuromuscular fatigue, determined using power outputs from CMJ between drills. In addition, whilst no changes in RPE were reported, the current findings suggest that athletes may have improved elements of metabolic and cardiopulmonary efficiency when completing the same relative session following the training period, with dampened responses of these measures observed under some conditions. Given individual drill intensities were re-calculated based on 30-15_{IFT} testing conducted prior to the second testing period; these findings may be linked to specific local and central adaptations, including greater efficiency at utilising aerobic and anaerobic sources of energy, reducing blood lactate accumulation and cardiorespiratory stress (McArdle, Katch, & Katch, 2007).

These current findings reveal that the arrangement of HIT exercises can influence the physiological responses throughout a training session. Within each protocol, we observed the greatest increase in $[La^{-}]_b$ accumulation and RPE occurred at different stages despite no substantial differences at the completion of each protocol. The current study observed the greatest acute $[La^{-}]_b$ and RPE changes occurred following either SL_{ACTREC} (protocol one) or $SHTL_{30HI}$ (protocol three). These two exercises incorporate either active recovery periods (SL_{ACTREC}) or increased running intensities ($SHTL_{30HI;}$ > 100% V_{IFT}) when compared to the remaining two exercises, likely attributing to the greater central and peripheral disturbance witnessed. It is probable that during the initial phases, if moderate levels of running intensity are met with reasonably adequate recovery periods, the initiation of the respiratory and circulatory systems may be delayed before commencement is essential to meet the excess oxygen requirements (Astrand, Astrand, Christensen, & Hedman, 1960). Indeed, despite possible individual variation, the initial rate of oxygen uptake, combined with the interaction of enzyme activation and intrinsic inertia in cellular metabolic signals may prevent excessive peripheral physiological disturbance and psychophysical stress during these lower intensity exercises (Jones & Burnley, 2009). Similar results were apparent when examining the cardiorespiratory responses during each protocol with HR_{90} highest when an active recovery was performed. Moreover, the accumulated HR_{90} was highly effected by the placement of exercises, with early incorporation of an active recovery increasing the cardiopulmonary demands of the session.

The current study observed *almost certain* increases in $[La^{-}]_b$ following $SL_{ACTREC,}$ with this exercise causing a peak in $[La^{-}]_b$ in two of the protocols. Currently, there is limited research evaluating the impact of exercise intensity during the recovery periods within HIT, however, it is suggested that an active recovery may initiate lower levels muscle oxygenation (Dupont et al., 2004b). For example, shorter time to exhaustion and moderately higher post- HIT $[La^{-}]_b$ values have been reported when athletes performed an active recovery [(15 s (120% maximal aerobic speed)/15 s (50% maximal aerobic speed)] when compared to a passive recovery (Dupont, Blondel, & Berthoin, 2003). This was suggested to be likely due to inadequate oxygen supply to reload myoglobin and haemoglobin in order to resynthesise phosphocreatine (Dupont & Berthoin, 2004; Dupont et al., 2004b). The current study also observed substantially higher RPE for SL_{ACTREC} when compared to $SHTL_{30}$ and $SHTL_{15,}$ however no differences were witnessed between $S_{LACTREC}$ and $SHTL_{30HI.}$ This is likely due to the higher running intensity during $SHTL_{30HI}$, causing greater psychophysical stress than shuttle-based HIT performed at lower intensities. During SL_{ACTREC} there was also substantial increases in $HR_{>90}$ compared to all other exercises. Further, when SL_{ACTREC} was introduced in the middle of the HIT protocol (one and two), there was an increase in accumulated HR_{90} for the protocol. As such, it appears that introducing active recovery into HIT strategies may increase the metabolic and cardiopulmonary demands of both current and subsequent HIT drills. Therefore, if practitioners are aiming to increase time above 90% $\dot{V}O_2max$ (often considered a primary promoter of cardiovascular adaptation) whilst maintaining shorter intervals, utilising an active recovery earlier in the HIT session will likely improve the desired outcomes (Buchheit & Laursen, 2013b; Dupont & Berthoin, 2004).

In contrast to other research (Dellal et al., 2010), the current study observed that shuttle-based HIT exercises did not appear to increase $[La^{-}]_b$ to the same degree as straight-lined HIT utilising active recovery. It is suggested that increased COD causes superior peripheral metabolic disturbance compared to straight-line running, resulting in a likely greater anaerobic energy contribution (Dellal et al., 2010). However the present study did not observe this, with the current findings demonstrating greater metabolic disturbance during HIT with active recovery rather than an increased COD requirement. Whilst there were still substantial increases in $[La^{-}]_b$ following these drills, the lower magnitude of increase observed is likely due to the work intensities being adjusted in the current study to incorporate the time lost for the COD task, rather than simply adding CODs (Buchheit, Haydar, Hader, Ufland, & Ahmaidi, 2011a). Indeed, the greatest physiological responses (from shuttle-based HIT) were observed following $SHTL_{30HI}$, likely due to the increased running intensity performed, somewhat overcoming this reduction in time. These findings confirm past observations that have reported similar or lower $[La^{-}]_b$ when the COD time is removed from the work intensity compared with straight-line HIT (Buchheit, 2011; Buchheit et al., 2011a). The current study observed similar findings when reporting HR_{90} and RPE. As previously reported, SL_{ACTREC} had a greater cardiorespiratory response (HR_{90}) than all shuttle-based HIT exercises. However, while no substantial differences were witnessed between $SHTL_{30}$ and $SHTL_{15}$, $SHTL_{30HI}$ resulted in substantially higher RPE and HR_{90} when compared to $SHTL_{15}$. As mentioned, this is likely due to a combination of the higher running intensity (during $SHTL_{30HI}$) and the time removed for the increased CODs during the 15m shuttle ($SHTL_{15}$), creating a greater disparity between intensities. Collectively, these findings suggest accumulation of $[La^{-}]_b$ and HR_{90} may be more sensitive to HIT incorporating active recoveries rather than HIT with greater mechanical (acceleration and deceleration) loads (Table 8.4). Moreover, if the aim is to increase peripheral disturbance during shuttle-based HIT, practitioners may need to increase the intensity of the running (compared to straight line) or aim to individualise the time removed for the acceleration and deceleration phases.

The current study observed no indication to suggest exacerbated acute neuromuscular fatigue was evident throughout the HIT protocols. Whilst there is little research assessing the acute neuromuscular responses during HIT, it is suggested that an increased anaerobic glycolytic energy contribution decreases force production due to increased fatigue of motor units and the musculoskeletal system (Vuorimaa, Virlander, Kurkilahti, Vasankari, & Hakkinen, 2006). However, the current study suggests this may not be evident during HIT protocols lasting 20 minutes or less, with no substantial evidence of any acute change in peak power output through each protocol. It has been proposed that there is a bell-shaped relationship between the intensity of an HIT session and the acute neuromuscular performance (Buchheit & Laursen, 2013a). Given the intensities of the prescribed running ranged from 80 – 105% V_{IFT} it is possible that these HIT strategies incurred a 'positive neuromuscular loading' despite a high anaerobic glycolytic energy contribution. Similarly, when examining the influence of tactical training undertaken before HIT, no substantial acute decrement in peak concentric power (or increased physiological disturbance) was evident when compared to those who initially performed HIT. Taken together, the findings of this study demonstrate differences in the physiological fatigue during the acute stages during and following HIT. For example, while there may be considerable metabolic fatigue resulting from HIT, neuromuscular fatigue maybe it less effected during the acute stages. These findings confirm some past studies in team sport which suggest, unlike endurance runners, these athletes may be able to tolerate low-volume HIT strategies, demonstrating minimal acute neuromuscular fatigue (Buchheit, 2012).

Lastly, this study aimed at assessing the physiological responses of rugby league athletes to complete HIT following an extended period of training (six-week pre-season block). Whilst the ability for these athletes to better tolerate these sessions was not conclusive (with no changes witnessed in RPE), it does appear that these athletes may have improved metabolic and cardiopulmonary efficiency with a dampened response of these measures witnessed following the training period. These results suggest athletes may become more effective at utilising aerobic and anaerobic energy sources at a given running intensity with regular training over an extended period (typical of the pre-season phase), however further research is needed to investigate the direct cause of these physiological changes.

CONCLUSIONS

The findings of this study demonstrate that the metabolic and cardiorespiratory responses are highly variable through the prescription of exercise intensity, recovery intensity and exercise duration. The current findings reveal that the arrangement and prescription of exercises are highly important when planning HIT. As such, it is important performance staff ruminate about the specific physiological focus of the session. For example, the primary aim of the session may be to induce cardiopulmonary adaptations. Therefore, including an active recovery earlier will elicit greater cardiorespiratory stress on ensuing exercise. However, this may come at the cost of quality high-intensity movements and greater exposure to higher mechanical loads. Taken together, it is apparent the implementation of HIT sessions needs to be structured as a function of the periodised aims of the physical program with concurrent training strategies taken into account (Yeo, Paton, Garnham, Burke, Carey, & Hawley, 2008). Importantly, this study observed no substantial differences between training groups completing HIT prior- and post- tactical training. Given it is often difficult to ideally periodise conditioning and tactical sessions to allow athletes to be in a recovered state prior to conditioning during pre-season, this finding provides evidence to suggest HIT may not be compromised from short, moderate-intensity tactical skills sessions. Finally, the results of this study suggest that following an extended training period, athletes may have improved efficiency at utilising aerobic and anaerobic energy sources with a dampened metabolic and cardiorespiratory response witnessed across some protocols.

LIMITATIONS

Whilst there may be limitations using $[La^{-}]_b$ concentration to evaluate the anaerobic glycolytic metabolic demand of HIT (e.g. large individual responses and poor association with muscle lactate) (Jacobs & Kaiser, 1982; Krustrup, Mohr, Steensberg, Bencke, Kjaer, & Bangsbo, 2006b), there is not yet an agreeable and established gold standard to assess anaerobic glycolytic energy contribution (Buchheit & Laursen, 2013a; Medbo, Mohn, Tabata, Bahr, Vaage, & Sejersted, 1988). As a result, $[La^{-}]_b$ still appears to be an appropriate measure to estimate anaerobic contribution during exercise. A further limitation was the absence of $[La^{-}]_b$ analysis during protocol two, which limits the understanding of this profile across that protocol.

The short tactical sessions (~30 mins) implemented in the current study may be less demanding than that incorporated during the pre-season phase of training (typically 45 – 90 minutes). While increasing the demands of these tactical session may result in greater metabolic and neuromuscular demands, further depleting glycolic stores, these findings are the first to suggest that HIT sessions following tactical sessions may not be as compromised as previously suggested. Future research may directly asses the metabolic effect of these tactical sessions conducted prior to HIT while further addressing the interplay between metabolic functions and mechanical changes in HIT sessions. Finally, it must be noted that a control group is absent from the current study and the results should be interpreted as such. Whilst this is often difficult and impractical within the current population, it would likely aid in the understanding of the direct physiological effect of the implemented protocols.

PRACTICAL APPLICATIONS

- When designing HIT sessions in team sports, it is important to establish the desired physiological outcome of the session as exercise arrangement may affect the specific adaptations from the session.
- Superior HIR distance had a greater effect on the acute metabolic demands during HIT sessions, than shorter shuttle exercises with increased mechanical loads (acceleration/ deceleration)
- Moderate-intensity tactical sessions undertaken prior to HIT sessions may not have as greater influence on the metabolic response as first suspected.

Chapter IX

Summary and Conclusions

OVERVIEW

This thesis has presented five studies that have extended the current knowledge regarding the appropriate methods to examine, monitor and prescribe HIT within an elite rugby league cohort. Initially, the reliability and usefulness of the 30-15$_{IFT}$ to examine PHIR capacity within rugby league players was assessed in *Chapter III* (Scott et al., 2015). Following this, *Chapter IV* investigated the validity and contributing factors to 30-15$_{IFT}$ performance within a similar cohort (Scott et al., 2016c). The purpose of these studies was to determine whether the 30-15$_{IFT}$ was an appropriate physical test to examine PHIR capacity in a mesomorphic athletic population. *Chapter V* then used these outcomes to provide a novel method to assess PHIR in team sport athletes (particularly collision-based sports) through the calculation of 'running momentum' (as the product of body mass and 30-15$_{IFT}$ performance). Additionally, this chapter demonstrated that both these measures could differentiate between competition levels (Scott, Dascombe, Delaney, Sanctuary, Scott, Hickmans, & Duthie, 2017a). *Chapter VI* (Scott, Thornton, Scott, Dascombe, & Duthie, 2017b) examined the practicality of the 30-15$_{IFT}$ to individualise relative speed and metabolic thresholds to quantify match-play outputs and imposed external loads. *Chapter VII* validated the use of these 30-15$_{IFT}$ derived speed thresholds to quantify training, demonstrating moderate to large associations between these external TL measures and criterion internal TLs. Finally, *Chapter VIII* (Scott, Dupont, Thornton, Delaney, Ballard, Hickmans, Dascombe, & Duthie, 2018) assessed the acute metabolic, cardiorespiratory and neuromuscular effects across a various HIT protocols in team sport athletes. This investigation provides practitioners a greater understanding on the arrangement of HIT drills within a session and the effect of concurrent tactical/technical training. In the final section of this thesis, the significant outcomes of the present series of studies are highlighted in the context of the current literature, whilst implications for future research are discussed.

RESEARCH OUTCOMES

Background

To physically prepare athletes for team sport competition requires a fundamental understanding of the processes and outcomes of the training stimulus provided. Practitioners must correctly assess the training outcome (physical testing), manipulate training prescription (training process) and review the dose-response relationship (training monitoring) in order to individualise their physical preparation and evaluate the program's success. However, due to the multifaceted nature of the physical demands of team sports, the interactions between these processes are highly complex. The current thesis has proposed a physical preparation feedback loop (Figure 9.1) as a method to conceptualise this interaction, with the current series of studies aimed at presenting new and novel methods to incorporate within this system.

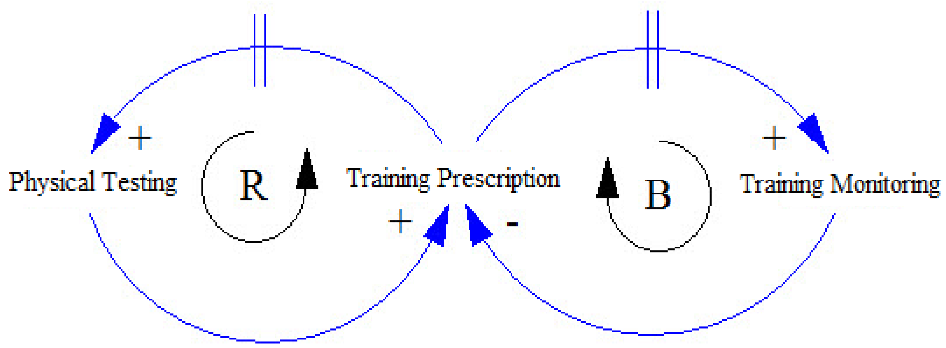

Figure 9.1: The physical preparation feedback loop as proposed by the current thesis. Training prescription (training process) is reinforced (R) by the feedback from physical testing (training outcome) and balanced (B) by the positive and negative training status of the athlete (training monitoring).

Physical Testing

When aiming to individualise the training process for athletes, it is important that the training outcome guides and reinforces training prescription (training process). The 30-15$_{IFT}$ has previously been demonstrated to be valid and reliable among basketball, handball, ice hockey, soccer and rugby union cohorts (Buchheit, 2008b; Buchheit et al., 2011b; Covic et al., 2016; Darrall-Jones et al., 2015; Scott et al., 2015). In addition, the 30-15$_{IFT}$ has been shown to elicit more homogenous physiological responses during HIT protocols than other criterion measures, such as the MSFT and UM-TT (Buchheit, 2008b).

Chapter III demonstrated that the reliability of the 30-15$_{IFT}$ was *very good*, with a TE of 0.36 $km{\cdot}h^{-1}$ (CV 1.9%) (Scott et al., 2015). This is similar to that reported previously by Buchhiet (2005b), who also demonstrated the test-retest reliability of the 30-15$_{IFT}$ to be *very good* (TE of 0.30 $km{\cdot}h^{-1}$ [CV 1.7%]) among 20 regional-to-national level European handball players. Despite the usefulness of the 30-15$_{IFT}$ being deemed '*marginal*', it must be noted that both the TE and SWC change were less than 1 stage of the test. As a result, this study demonstrated that a change as small as 0.5 $km{\cdot}h^{-1}$ (1 stage) in V_{IFT} could be interpreted as substantial or '*real*', giving performance staff a measure of physiological performance change. Separately, *Chapter IV* examined the physiological factors that contribute to V_{IFT}, demonstrating that the 30-15$_{IFT}$ is a valid test of PHIR among a typically mesomorphic population (Scott et al., 2016c). Furthermore, whilst this test appears to be related to many physiological capacities, it appears highly aerobically-dependent, with improvements in V_{IFT} performance most likely through an increased aerobic capacity. Importantly, the physiological contribution of 30-15$_{IFT}$ performance varied between positional groups in rugby league, influenced by the varying physiological profiles between positions. *Chapter III and IV* provide a strong foundation for practitioners to confidently use the 30-15$_{IFT}$ to assess PHIR among mesomorphic athletes. Taken together, these chapters add to past findings (Buchheit, 2008b; Buchheit et al., 2009a; Darrall-Jones et al., 2015) outlining that 30-15$_{IFT}$ performance is the product of various physiological factors and is influenced by the inter-play between these capacities during HIR. Resultantly, these studies demonstrate that the prescription of HIT utilizing V_{IFT} controls for these individual capacities across squads that are heterogeneous in anthropometric characteristics.

Previously it has been suggested that heavier team sport athletes would experience greater mechanical and metabolic loads throughout the 30-15$_{IFT}$ compared to previously assessed cohorts (e.g. soccer or European handball players) (Darrall-Jones et al., 2015). Indeed, the ability to change direction appears to be negatively affected by a greater body mass, due to the increased inertia and higher proportional impulse required to decelerate and re-accelerate (Frost et al., 2010). Past data has observed that V_{IFT} remains relatively stable in rugby union players ranging from U16 to senior competitions, despite a continued increase in body mass (Darrall-Jones et al., 2015). Performance staff in collision-based sports aim to increase the body mass (specifically lean mass) of athletes over time to benefit performance. As these sports typically comprise athletes with heterogeneous anthropometrical characteristics, an evaluation of the interaction between running performance and body mass appears vital, particularly given the suggested greater mechanical and metabolic demands of heavier athletes during shuttle based conditioning (Enoka, 2002). *Chapter V* provided a new and novel method to calculate this interaction, with p_{IFT} (the product of V_{IFT} and body mass) expressing the inter-play of this relationship. This chapter demonstrated that p_{IFT} was reliable and able to differentiate between performance levels, which is highly useful in collision-based sports given the heterogeneity in body size. This analysis is useful when monitoring an individual over time as they may experience large changes in body mass due to morphological adaptation, whilst it references the ability to overcome the prolonged inertial effect of PHIR rather than representing the specific physiological capacities incorporated in V_{IFT}. *Chapter V* concluded that the use of the p_{IFT} and V_{IFT} established from the 30-15_{IFT}, provided an index of PHIR performance that can separately distinguish between levels of competition and positional groups in rugby league. Collectively, these studies add to the body of literature, suggesting the 30-15_{IFT} provides a suitable test to examine more specific elements of PHIR performance in collision sports.

Training Monitoring

Athlete training monitoring is established on our understanding of the relationship between the training process and training outcome (see Figure 1.1 in *Chapter I*). The current thesis aimed at providing new methods to quantify the training process with a specific emphasis on HIR. To account for the known limitations of using absolute speed zones to quantify physical running demands of team sports (Abt & Lovell, 2009; Clarke et al., 2015; Gabbett, 2015), *Chapter VI* (Scott et al., 2017b) examined the use of relative speed zones to quantify running loads whilst *Chapter VII* assessed the construct validity of these proposed zones. Currently there is little consensus on the absolute GPS speed zones used to define running output in team sports (particularly HIR), with no physiological justification for their definition. Past thresholds have been largely based off maximal speed (Gabbett, 2015), despite a greater relationship witnessed between VT_2 and HIR (Abt & Lovell, 2009; Clarke et al., 2015). Given that HIR running is considered an important measure in physical match-play output and commonly reported (McLellan & Lovell, 2013; Sirotic et al., 2009), it appears that utilising an athletes ventilatory thresholds better classifies these intensities (Abt & Lovell, 2009; Clarke et al., 2015). Yet, there are limitations when establishing individual ventilatory thresholds, most of all, the regular laboratory testing required across large squads (Abt & Lovell, 2009). Hence, *Chapter VI* explored using estimated individual ventilatory thresholds based on the 30-15$_{IFT,}$ based on the known relationship between this test and the VT_1 and VT_2 thresholds (Buchheit et al., 2009a).

When examining the differences in match-play output across positions using relative speed thresholds (derived from the 30-15$_{IFT}$) or absolute methods, it was established that absolute speed thresholds underestimate the HIR (Scott et al., 2017b). This is in agreement with findings reported in soccer and rugby union (Abt & Lovell, 2009; Clarke et al., 2015). Taken together, these studies conclude that the speed at which players exceed HIR is dependent on individual capacities and attributes and therefore applying relative speed thresholds is warranted. *Chapter VI* proposes a new method to easily manipulate relative speed thresholds that is more precise to MIR and HIR than percentage based maximal speed thresholds (Scott et al., 2017b). The validity of specific external load measures have been questioned due to both the lack of physiological justification and/or their association with constructs of internal training load (Abt & Lovell, 2009; McLaren et al., 2018). *Chapter VII* demonstrated that the V_{IFT}-derived relative speed thresholds proposed in *Chapter VI* relate well to various measures of internal training load, providing sufficient evidence to deem these thresholds valid in team sports.

Collectively, the findings from these chapters (*VI and VII*) provide a valid and novel method to individualise relative speed thresholds in team sports athletes through the use of a field-based test, which increases the practicality of employment across large squads. Taken together, when evaluating the dose-response relationship of HIT and concurrent field tactical/technical sessions, the use of relative thresholds allows for more precise monitoring of external training loads as they account for the individual demands placed upon team sport athletes. As such, the use of relative thresholds may allow performance staff to more appropriately monitor the physical running loads of individual athletes.

Training Prescription

Reference Speed based HIT

It has been established (Buchheit, 2008b; Scott et al., 2015; Scott et al., 2016c) that V_{IFT} provides a suitable HIR prescription reference speed across athletes with heterogenous physiological profiles. When examining the acute metabolic and neuromuscular responses of common HIT protocols employed within team sports, *Chapter VIII* (Scott et al., 2018) demonstrated that the arrangement of HIT exercises can influence the physiological responses throughout a training session. For example, a reported substantial increase in $[La^{-}]_b$ accumulation and RPE occurred at different stages within a HIT session based on the arrangement of HIT exercises despite no differences witnessed at the completion of each session. As such, performance staff must decide on the specific physiological focus of the session. For instance, if the primary aim of the session may be to induce metabolic adaptations, including an active recovery earlier will increase the metabolic stress at an earlier period. However, this may come at the cost of quality high-intensity movements and greater exposure to higher mechanical loads.

It has been suggested that incorporating active recovery produces lower levels of muscle oxygenation, reducing the available oxygen to reload myoglobin and haemoglobin as well as to resynthesise phosphocreatine, subsequently resulting in earlier fatigue (Dupont &

Berthoin, 2004; Dupont et al., 2004b). However, this research has been conducted in isolation with little known on the effect that these HIT strategies have when conducted prior to and following other HIT methods. Importantly, *Chapter VIII* (Scott et al., 2018) revealed that accumulation of $[La^{-}]_b$ may be more sensitive to HIT incorporating active recoveries rather than HIT with greater mechanical (acceleration and deceleration) loads independent of their arrangement in the session. Further, introducing active recovery based HIT earlier in the session was shown to elicit an increased accumulated HR_{90} for the session. These findings provide new evidence suggesting that if practitioners are aiming to increase time above 90% $\dot{V}O_2max$ [often considered a primary promoter of cardiovascular adaptation (Buchheit & Laursen, 2013b)] whilst maintaining shorter intervals, manipulation of these HIT strategies will likely improve the desired outcomes (Buchheit & Laursen, 2013b; Dupont & Berthoin, 2004). Collectively, this study demonstrated that practitioners should develop sessions with the overall physiological adaptation aims in mind.

It has been observed that residual neuromuscular fatigue post-HIT may inhibit the rate of force development during subsequent training sessions, potentially compromising planned neuromuscular loadings (Blazevich, 2012). In contrast, *Chapter VIII* demonstrated that HIT performance was not compromised from any acute fatigue arising from moderate intensity tactical sessions. Indeed, there were no differences in any cardiorespiratory, metabolic or neuromuscular response between athletes those who completed tactical training before HIT and those that undertook HIT immediately following warm up. As it is often difficult to ideally periodise conditioning and tactical sessions in order to allow athletes to be in a recovered state prior to conditioning, these findings provide new evidence to suggest acute physiological responses may not be effected by tactical and technical training.

Additionally, *Chapter VIII* aimed at assessing the physiological responses to HIT in rugby league athletes following an extended period of training (six-week pre-season block). Whilst the ability for these athletes to better tolerate (no changes in RPE) these sessions was not conclusive, it does appear that these athletes may have improved metabolic and cardiopulmonary efficiency. Indeed, the current study observed a dampened response of these measures following the training period, despite an increase in the work (distance) prescribed during the re-testing period (due to improved fitness). These findings may be linked to specific local and central adaptations, reducing blood lactate accumulation and cardiorespiratory stress (McArdle et al., 2007). Taken together, the findings of *Chapter VIII* recommends that HIT sessions need to be structured as a function of the periodised aims of the physical program with concurrent training strategies taken into account (Yeo et al., 2008).

Lastly, this thesis aimed at presenting new strategies to prescribe HIT within mesomorphic team sport athletes. Previously, Buchhiet (2011) published an example of how the 30-15$_{IFT}$ may be prescribed across team sport athletes (Table 9.1). However, given the heterogeneity of team sport athletes, this may not be applicable across all sports. While it has been suggested that a higher body mass is beneficial for collision sport athletes due to the proportional increase in momentum they may achieve prior to contact (Barr et al., 2014; Duthie, 2006), this would result in greater inertia and require more force to decelerate during the braking phase of a COD task. In turn, this would increase the neuromuscular and metabolic stress which results from shuttle based HIT. Further, given collision-based 180-degree sports (i.e. rugby league, rugby union, American football) have differing physical demands to 360-degree sports (i.e. soccer, Australian football, Gaelic football), these athletes are likely to require differing methods of physical field conditioning. As such, Table 9.2 provides a progression of these V_{IFT}-based HIT strategies that may be more specific to the conditioning of these collision based sports where shorter, repeated explosive efforts are common.

Table 9.1: Original V_{IFT}-based HIT strategies developed by Buchheit (2011).

Adaptations	Running time	Running intensity (%V_{IFT})	Recovery duration	Recovery intensity (% V_{IFT})	Running modality	Set length	Number of Sets	Recovery between Sets
Central	3 min	85-88%	-	-	Straight line	-	5 to 6	3'
	45 s	90%	15 s	Passive	Straight line	7'-8'	2 to 3	3'
	30 s	90%	15 s	passive	Straight line	7'-8'	2 to 3	3'
	30 s	90%	30 s	40%	Straight line	>12	2	3'
	30 s	93%	30 s	passive	Shuttle 40m	12'	2 to 3	3'
	15 s	100%	15 s	passive	Straight line	10'	2 to 3	3'
	15 s	95%	15 s	25%	Shuttle 40m	15'	2	3'
Peripheral	20 s	95%	20 s	passive	Straight line	7'-8'	2	6-7' active
	20 s	90%	20 s	45%	Shuttle 30m	7'-8'	2	6-7' active
	20 s	95%	15 s	passive	Shuttle 30m	7'-8'	2	6-7' active
	15 s	100%	15 s	passive	Shuttle 40m	7'-8'	2	6-7' active
	15 s	95%	15 s	25%	Straight line	7'	2	6-7' active
	15 s	95%	10 s	passive	Shuttle 40m	7'	2	6-7' active
	10 s	90%	10 s	passive	Shuttle 10m	6'	2	6-7' active
	10 s	95%	10 s	passive	Straight line	6'	2	6-7' active
	3 s	sprint	17 s	passive	20m sprint or 2 x 10m shuttle	6'	2	6-7' active

Table 9.2: V_{IFT}-based HIT strategies developed as a result of *Chapter VI to VIII*.

Level	Progression	Running time	Running intensity (% V_{IFT})	Recovery duration	Recovery intensity (% V_{IFT})	Running modality	Repetitions	Sets	Recovery between Sets	Total Length
Level 1	1a	15 s	85%	15 s	Passive	40m Shuttle	6	2	2 min	8 min
Level 2	2a	20 s	90%	20 s	Passive	30m Shuttle	4	2	2 min	7 min 20s
	2b	30 s	85%	30 s	Passive	30m Shuttle	5	2	2 min	12 min
	2c	30 s	80%	30 s	Active (56% V_{IFT})	30m Shuttle	4	2	2 min	10 min
	2d	30 s	85%	30 s	Passive	30m Shuttle	4	2	2 min	10 min
	2e	30 s	85%	30 s	Active (60% V_{IFT})	30m Shuttle	4	2	2 min	10 min
	2f	30 s	90%	30 s	Passive	30m Shuttle	4	2	2 min	10 min
Level 3	3a	30 s	95%	30 s	Passive	30m Shuttle	3	2	2 min	8 min
	3b	30 s	80%	15 s	Passive	30m Shuttle	4	2	2 min	8 min
	3c	30 s	85%	15 s	Passive	30m Shuttle	4	2	2 min	8 min
	3d	30 s	85%	30 s	Passive	15m Shuttle	4	2	2 min	10 min
Level 4	4a	30 s	90%	15 s	Passive	30m Shuttle	4	2	2 min	8 min
	4b	15 s	105%	15 s	Passive	30m Shuttle	8	2	2 min	10 min
	4c	30 s	95%	15 s	Passive	30 m Shuttle	4	2	2 min	8 min

CONCLUSIONS AND RECOMMENDATIONS

In order to maximise the individual physiological adaptation to the high-intensity intermittent demands of team sports, athletes should be systematically overloaded using a range of training modalities including tactical/technical, speed, agility and strength and power training. As such, HIT is often incorporated in to the physical curriculum of team sports, aimed at progressively overloading these physiological functions to maximise daily performance adaptations, as well as preparing athletes for future training stimulus. It is important that HIT prescription results in homogenous physiological responses across large squads, overcoming the heterogeneity which results from differences in athlete body sizes and physical capacities. However, employing a physical test that provides both a training prescription reference speed while possessing suitable reliability and validity among heterogeneous athletes has previously proven to be difficult.

This thesis examined the validity, reliability and usefulness of the 30-15$_{IFT}$ among a primarily mesomorphic population, demonstrating the test to be appropriate in the assessment of PHIR while outlining the contributing physiological factors to V_{IFT}. Additionally, for collision-based sport athletes that require greater lean muscle mass (and consequently body mass), it may be more appropriate to monitor the interaction of this change between mass and physiological performance. Understanding the capacity for junior and senior athletes to perform PHIR with greater body mass may allow practitioners to better gauge the physical progression of their athletes. Indeed, this analysis may be useful when monitoring an individual over time as they may experience large changes in body mass due to morphological adaptation. Further, this interaction can better distinguish levels of competition and positional groups across team sports where the range of athlete body mass is great.

Separately, when reviewing the HIR loads imposed on athletes, it is important to consider the applied thresholds relative to their physiological capacities. Utilising laboratory derived individual physiological-based thresholds to examine HIR has shown great promise, although it may be limited due to the impracticality of regular laboratory testing for large squads. Therefore, utilising individual physiological-based thresholds from the 30-15$_{IFT}$ may provide a more practical indicator of this HIR loads, particularly for those with lower fitness levels. As such, performance staff may gain greater insight into the volume of running performed at higher relative intensities allowing for more precise monitoring of this load and feedback to the training process.

The training process (prescription) is an integral foundation for any team sport physical program. Utilising HIT may be a time efficient method to effectively target specific physiological adaptation. However, whilst individual drills may aim to elicit certain physiological responses, understanding the inter-play between subsequent HIT protocols on metabolic and neuromuscular responses is important. Through deliberately manipulating HIT protocols, it is possible to alter the physiological demands of a HIT session, which may evoke diverse metabolic, neuromuscular and cardiopulmonary responses and adaptation. However, it is vital practitioners review with the training feedback loop, understanding the inter-play between the training outcome and training monitoring on the training process.

DIRECTIONS FOR FUTURE RESEARCH

The outcomes of the present series of studies suggest that areas for further investigation include:

- Examine the influence and relationship between p_{IFT} and V_{IFT} and measures of match performance in team sports. Importantly, this study may aim at determining if an increase in the product of mass and fitness has a differential effect of match performance and outcome.
- Evaluate the relationship between $30\text{-}15_{IFT}$-based relative thresholds and tactical match performance. This study may aim to further develop the construct validity of relative thresholds through the relationship between running output and match-play tactical performance.
- Observe the relationship between longitudinal $30\text{-}15_{IFT}$-based ventilatory threshold loads and injury and illness in team sports. Following on from the work of the current thesis and suggested future studies above, this research may attempt to observe if relative thresholds are more sensitive to detect injury and illness risk than absolute methods.
- Examine the interaction between metabolic responses with changes in HIT mechanical power (acceleration/ deceleration cost). This study may investigate the most appropriate methods to prescribe HIT to elicit a given metabolic response.

Chapter X

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Chapter XI

Appendices

Appendix I

Effect of Playing Level on 30-15 Intermittent Fitness Test Performance in Rugby League

This chapter is based on the peer-reviewed paper a***ccepted and presented*** at Exercise and Sport Science Australia (ESSA) Conference, Adelaide; 2014:

Scott, T. J., Delaney, J. A., Duthie, G. M., Sanctuary, C. E., Ballard, D. A., Hickmans, J. A. & Dascombe, B. J. (2014). Effect of playing level on 30-15 Intermittent Fitness test performance in rugby league.

Statement of Joint Authorship and Author Contribution

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- *Critical revision of the manuscript*

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INTRODUCTION

The 30-15$_{IFT}$ is an intermittent incremental shuttle-run test that determines a maximal measure of intermittent fitness. An important benefit of the 30-15$_{IFT}$ is that the final velocity can be used to individually prescribe high-intensity intermittent running during conditioning. Past data is available on the 30-15$_{IFT}$ in various field-based team sports, however, no data has reported on the use of the 30-15$_{IFT}$ in rugby league. The current study reports data for the 30-15$_{IFT}$ performance within rugby league squads across specific playing groups (age defined).

METHODS

Rugby league players from the Newcastle Knights U16 (n=20), U18 (n=21), National Youth Championship (U20, NYC; n=28) and National Rugby League (NRL; n=24) playing groups completed the 30-15 IFT test at the end of the general preparation phase of the 2012 and 2013 pre-seasons. A one-way ANOVA with LSD *post-hoc* tests determined if there was any significant effect of playing level on 30-15$_{IFT}$ performance within rugby league

RESULTS

30-15$_{IFT}$ performance differed across the U16 (18.5 ± 1.0 $km \cdot h^{-1}$), U18 (18.6 ± 1.2 $km \cdot h^{-1}$), NYC (18.9 ± 1.0 $km \cdot h^{-1}$) and NRL (19.7 ± 0.6 $km \cdot h^{-1}$) playing groups. This data demonstrated a significant ($p<0.05$) effect of age on 30-15$_{IFT}$ running performance in rugby league. Individual significant differences were present between the 30-15$_{IFT}$ performance of the NRL and the U16 ($p<0.001$) and U18 ($p=0.001$) and NYC ($p=0.006$) playing squads.

CONCLUSIONS

The data demonstrates that 30-15$_{IFT}$ performance can distinguish between specific playing groups in well-trained rugby league players. The significant effect of age on the 30-15$_{IFT}$ demonstrates that intermittent fitness continues to develop with training age and can discriminate between performance levels. This aids the prescription of training and provides a valuable tool in the differentiation of athletic preparation across specified playing groups. However, future research should examine the interaction with mass and V_{IFT} given the physical development of athletes from youth the senior selection.