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Manuscript Title: The validity and contributing physiological factors to 30-15 Intermittent Fitness Test performance in Rugby League

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Authors:
Tannath J. Scott [1, 2], Grant M. Duthie [3], Jace A. Delaney [1], Colin E. Sanctuary [1], David A. Ballard [4], Jeremy A. Hickmans [2] and Ben J. Dascombe [1, 5]

Affiliations
[1] Applied Sport Science and Exercise Testing Laboratory
Faculty of Science and Information Technology
University of Newcastle
Ourimbah, NSW 2258

[2] Performance Sciences Department
Brisbane Broncos Rugby League Club
Red Hill, QLD 4059

[3] Institute of Sport, Exercise and Active Living (ISEAL)
Victoria University
Footscray, VIC 3011

[4] Queensland Reds Rugby Union,
Herston, QLD 4006

[5] Department of Rehabilitation, Nutrition and Sport,
School of Allied Health,
LaTrobe University,
Bundoora, VIC 3083

Corresponding Author:
Mr. Tannath Scott
Performance Sciences Department
Brisbane Broncos Rugby League Club
1/92 Fulcher Rd, Red Hill
Ph: +61 2 423695386
Email: TannathS@broncos.com.au

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ABSTRACT

This study examined the validity of the 30-15 Intermittent Fitness Test (30-15_{IFT}) within rugby league. Sixty-three Australian elite and junior-elite rugby league players (22.5 ± 4.5 yr, 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 (MSFT) and power (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 predict individual final velocity (V_{IFT}) and change 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 during periods of match play. These efforts include repeated sprints, prolonged high-intensity running (PHIR) (considered an extended period of exercise incorporating repeated high-intensity running interspersed with phases of recovery), jumping, tackling and/or collisions (4, 27, 38), typically occurring at decisive moments during match-play (1). Subsequently, the ability to repeat high-intensity efforts is a desirable physiological attribute. High-intensity interval training (HIT) is commonly used as an effective means to improve the physiological qualities (including cardiorespiratory, metabolic and neuromuscular related elements) associated with high-intensity efforts (12, 13). HIT sessions have been typically prescribed using an individual's maximal aerobic capacity ($\dot{V}O_2max$) 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) (32), or the Yo-Yo Intermittent Recovery Test 1 (Yo-Yo IRT1) and 2 (Yo-Yo IRT2) (3). Interestingly, the limitations concerning the ability to test these qualities (such as PHIR) and subsequently prescribe movement specific HIT protocols have recently been recognized (8, 33). 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) (25). 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 (8, 29).

The 30-15 Intermittent Fitness Test (30-15_{IFT}) is a graded intermittent shuttle based field test that is both valid and reliable in the individual assessment of PHIR ability (8, 25, 33). The 30-15_{IFT} incorporates many physiological capacities associated within team sports performance;

including, individual players' inter-effort recovery, acceleration, deceleration and change of direction (COD) ability, aerobic capacity, PHIR ability (8, 25, 33). In addition, the final running velocity achieved in the 30-15$_{IFT}$ (V_{IFT}) has been demonstrated to provide lower inter-individual differences in the prescription of HIT than previous methods (8). As a result, when compared to prescribing HIT based off an individual's velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$), the use of V_{IFT} has been shown to elicit greater homogenous cardiorespiratory responses during HIT (6, 8). 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 (1, 39). 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 (modified from running to ice skating) cohorts (8, 14). Compared to straight line running, the 180 degree COD required for shuttle running typical of HIT training may elicit higher heart rate (HR), rating of perceived exertion and blood lactate due to greater anaerobic energy requirement (11, 15). 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 (20). Due to this, it has been suggested that heavier team sport athletes 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) (16). Therefore, it is important that the validity of the 30-15$_{IFT}$ 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), multi-stage fitness test (estimated $\dot{V}O_2$max), 2000-m time trial (average aerobic speed), 40-m maximal sprint (maximal speed) and 5-0-5 test (change of direction 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. Therefore 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 were selected to undertake assessment of repeated-sprint ability and laboratory assessment of maximal oxygen uptake ($\dot{V}O_2max$). The maximal oxygen uptake 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 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 yr, 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 yr, 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 National Rugby League (NRL) competition (n=37), and players competing in the National Youth Competition (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 yr, 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.

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). The only distinction was the 2000-m time trial, which was performed in the afternoon (1500 – 1700). All sessions were performed in temperatures between 20-24°C. Each subject completed testing over 3 separate sessions with at least 48 hours 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 Multi-Stage Fitness Test [MSFT]) players wore typical training monitoring equipment (e.g. heart rate 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 (19). Lean mass index (LMI) was calculated as per methods previously described (36).

Aerobic Capacity and Power Measures

Maximal aerobic capacity was assessed through the MSFT as previously reported (32). 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%) (23). 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) (23). Change of direction ability was measured using the 505 agility test as per (18). 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 $30\text{-}15_{IFT}$ 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 $30\text{-}15_{IFT}$ running velocity (V_{IFT}) (8). Maximal aerobic capacity ($\dot{V}O_2max_{30\text{-}15IFT}$) was estimated as per Buchheit (8).

Heart Rate Measurement

Heart rate (HR) 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 (24).

Maximal Oxygen Uptake

A maximal graded continuous running test was performed on an electronic treadmill (Cardiovit 100; Schiller, Baar, Switzerland) where $\dot{V}O_2$max 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, $\dot{V}O_2$max, CO_2 output) were continuously recorded with a commercially available system (Breath-by-Breath Metabolic Measurement; Sensor Medic MSE, Rungis, France). $\dot{V}O_2$max was determined by the criteria described by Taylor et al. (37), and was classed as a plateau in $\dot{V}O_2$max despite an increase in running speed and HR >90% of the predicted maximal value. The velocity associated with $\dot{V}O_2$max (v$\dot{V}O_2$max) was the lowest running speed that elicited a $\dot{V}O_2$ value equal to $\dot{V}O_2$max (5).

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 30-15_{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 (26).

In order to determine the combined effect of the chosen variables on 30-15_{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 1, while Pearson correlations with V_{IFT} are presented in Figure 1 and 2.

INSERT TABLE 1 AROUND HERE

INSERT FIGURE 1 AROUND HERE

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*).

INSERT FIGURE 2 AROUND HERE

Physiological Contributing Factors

The stepwise multiple-regression analysis revealed that 71.8% of the adjusted variance in 30-15_{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 30-15$_{IFT}$ 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.

INSERT TABLE 2 AROUND HERE

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 in 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} (8, 9, 25). However, these studies have utilised participants of relative homogeneity, and few that fit a mesomorphic physique (17). 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 (7, 8, 31), 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 (2, 21, 34, 35). 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 (25). 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 (8, 10, 16). 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 (8) reported that 75% of the variance of V_{IFT} (r= 0.87) could be explained from counter-movement jump (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 (8, 25), 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 predictor of PHIR ability (R^2 = 0.62). Following the theoretical physiological model of the 30-15 test (9), 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 (7-10).

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$\dot{V}O_2$max. 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 (17) 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 physiological functions 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 (30, 34) and reported PHIR ability (22) 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 (8) 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 (39) 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 (35, 39). Kempton et al., (28) 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 seconds recovery) per minute of match play than adjustables and outside backs (1). 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 (8), 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.

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} (9, 16) 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.

REFERENCES

1. Austin DJ, Gabbett TJ, and Jenkins DJ. Repeated high-intensity exercise in a professional rugby league. *J Strength Cond Res* 25: 1898-1904, 2011.
2. Baker DG and Newton RU. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *J Strength Cond Res* 22: 153-158, 2008.
3. Bangsbo J. *Fitness Training in Football—A Scientific Approach.* Bagsværd, Denmark: HO+Storm, 1994, pp 1-336.
4. Bangsbo J. Physiology of intermittent exercise, in: *Exercise and Sport Science*. WE Garrett, DT Kirkendall, eds. Philadelphia: Lippincott, Williams & Wilkins, 2000, pp 53-65.
5. Billat LV. Interval training for performance: a scientific and empirical practice. Special recommendations for middle- and long-distance running. Part I: aerobic interval training. *Sports Med* 31: 13-31, 2001.
6. Billat LV and Koralsztein JP. Significance of the velocity at VO2max and time to exhaustion at this velocity. *Sports Med* 22: 90-108, 1996.

7. Buchheit M. 30-15 Intermittent Fitness Test and repeated sprint ability. *Science & Sports* 23: 26-28, 2008.
8. Buchheit M. The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. *J Strength Cond Res* 22: 365-374, 2008.
9. Buchheit M. The 30–15 intermittent fitness test: 10 year review. *Myorobie J* 1 2010.
10. Buchheit M, Al Haddad H, Millet GP, Lepretre PM, Newton M, and Ahmaidi S. Cardiorespiratory and cardiac autonomic responses to 30-15 intermittent fitness test in team sport players. *J Strength Cond Res* 23: 93-100, 2009.
11. Buchheit M, Bishop D, Haydar B, Nakamura FY, and Ahmaidi S. Physiological responses to shuttle repeated-sprint running. *Int J Sports Med* 31: 402-409, 2010.
12. Buchheit M and Laursen PB. High-intensity interval training, solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load and practical applications. *Sports Med* 43: 927-954, 2013.
13. Buchheit M and Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. *Sports Med* 43: 313-338, 2013.
14. Buchheit M, Lefebvre B, Laursen PB, and Ahmaidi S. Reliability, usefulness, and validity of the 30-15 Intermittent Ice Test in young elite ice hockey players. *J Strength Cond Res* 25: 1457-1464, 2011.
15. Buchheit M, Millet GP, Parisy A, Pourchez S, Laursen PB, and Ahmaidi S. Supramaximal training and postexercise parasympathetic reactivation in adolescents. *Med Sci Sports Exerc* 40: 362-371, 2008.
16. Darrall-Jones J, Roe G, Carney S, Clayton R, Phibbs P, Read D, Weakley J, Till K, and Jones B. The Effect of Body Mass on the 30-15 Intermittent Fitness Test in Rugby Union Players. *Int J Sports Physiol Perform*, 2015.
17. Delaney JA, Scott TJ, Ballard DA, Duthie GM, Hickmans JA, Lockie RG, and Dascombe BJ. Contributing Factors to Change-of-Direction Ability in Professional Rugby League Players. *J Strength Cond Res* 29: 2688-2696, 2015.
18. Draper JA and Lancaster MG. The 505 test: a test for agility in the horizontal plane. *Aust J Sci Med Sport* 17: 15-18, 1985.
19. Durnin JV and Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br J Nutr* 32: 77-97, 1974.
20. Frost DM, Cronin J, and Newton RU. A biomechanical evaluation of resistance: fundamental concepts for training and sports performance. *Sports Med* 40: 303-326, 2010.
21. Gabbett TJ, Jenkins DG, and Abernethy B. Relationships between physiological, anthropometric, and skill qualities and playing performance in professional rugby league players. *J Sports Sci* 29: 1655-1664, 2011.
22. Gabbett TJ, Jenkins DG, and Abernethy B. Relative importance of physiological, anthropometric, and skill qualities to team selection in professional rugby league. *J Sports Sci* 29: 1453-1461, 2011.
23. Gabbett TJ, Kelly JN, and Sheppard JM. Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res* 22: 174-181, 2008.
24. Gabbett TJ, Stein JG, Kemp JG, and Lorenzen C. Relationship between tests of physical qualities and physical match performance in elite rugby league players. *J Strength Cond Res* 27: 1539-1545, 2013.
25. Haydar B, Haddad HA, Ahmaidi S, and Buchheit M. Assessing inter-effort recovery and change of direction ability with the 30-15 intermittent fitness test. *J Sports Sci Med* 10: 346-354, 2011.

26. Hopkins WG. How to interpret changes in an athletic performance test. *Sport sci* 8: 1-7, 2004.
27. Johnston RD, Gabbett TJ, and Jenkins DG. Applied sport science of rugby league. *Sports Med* 44: 1087-1100, 2014.
28. Kempton T, Sirotic AC, Rampinini E, and Coutts AJ. Metabolic power demands of rugby league match play. *Int J Sports Physiol Perform* 10: 23-28, 2015.
29. Krustrup P, Mohr M, Ellingsgaard H, and Bangsbo J. Physical demands during an elite female soccer game: importance of training status. *Medicine and Science in Sports and Exercise* 37: 1242-1248, 2005.
30. McLellan CP and Lovell DI. Performance analysis of professional, semiprofessional, and junior elite rugby league match-play using global positioning systems. *J Strength Cond Res* 27: 3266-3274, 2013.
31. Perandini LAB, Chimin N, Okuno J, Lima JRP, Buchheit M, and Nakamura F. Parasympathetic withdrawal during 30-15 intermittent fitness test correlates with its' maximal running speed in male handball players. *Journal of Exercise Physiology-online* 12: 29-39, 2009.
32. Ramsbottom R, Brewer J, and Williams C. A progressive shuttle run test to estimate maximal oxygen uptake. *Br J Sports Med* 22: 141-144, 1988.
33. Scott TJ, Delaney JA, Duthie GM, Sanctuary CE, Ballard DA, Hickmans JA, and Dascombe BJ. Reliability and Usefulness of the 30-15 Intermittent Fitness Test in Rugby League. *J Strength Cond Res* 29: 1985-1990, 2015.
34. Sirotic AC, Coutts AJ, Knowles H, and Catterick C. A comparison of match demands between elite and semi-elite rugby league competition. *J Sports Sci* 27: 203-211, 2009.
35. Sirotic AC, Knowles H, Catterick C, and Coutts AJ. Positional match demands of professional rugby league competition. *J Strength Cond Res* 25: 3076-3087, 2011.
36. Slater GJ, Duthie GM, Pyne DB, and Hopkins WG. Validation of a skinfold based index for tracking proportional changes in lean mass. *Br J Sports Med* 40: 208-213, 2006.
37. Taylor HL, Buskirk E, and Henschel A. Maximal oxygen intake as an objective measure of cardio-respiratory performance. *J Appl Physiol* 8: 73-80, 1955.
38. Twist C, Highton J, Waldron M, Edwards E, Austin D, and Gabbett TJ. Movement demands of elite rugby league players during Australian National Rugby League and European Super League matches. *Int J Sports Physiol Perform* 9: 925-930, 2014.
39. Waldron M, Twist C, Highton J, Worsfold P, and Daniels M. Movement and physiological match demands of elite rugby league using portable global positioning systems. *J Sports Sci* 29: 1223-1230, 2011.

FIGURE LEGEND

Figure 1. The correlations between V_{IFT} and various anthropometrical and physiological measures (mean +/- 95% CI) (LMI – Lean Mass Index).

Figure 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). * VO_2max and RSA tests (n=9).

TABLES

Table 1. Descriptive measures (mean ± SD) for all measured variables taken from the testing battery.

Variable	Mean	± SD	95% CI
Anthropometry			
Age (yrs)	22.5	4.6	21.4 – 23.6
Mass (kg)	96.1	9.6	93.8 – 98.5
Skinfolds (mm)	71.1	18.9	66.4 – 75.7
Lean Muscle Index (kg)	54.3	5.2	53.0 – 55.5
Speed and Change of Direction			
10-m Speed (s)	1.66	0.07	1.65 – 1.68
40-m Speed (s)	5.17	0.19	5.13 – 5.22
Average Acceleration ($m \cdot s^{-2}$)	3.63	0.29	3.55 – 3.70
Average Maximal Velocity ($m \cdot s^{-1}$)	8.88	0.40	8.78 – 8.99
505 test (s)	2.33	0.15	2.29 – 2.37
Maximal Aerobic Power			
$30\text{-}15_{IFT}$ ($km \cdot h^{-1}$)	18.4	0.9	18.2 – 18.6
$30\text{-}15_{IFT}$ (VO_2max) ($ml \cdot min^{-1} \cdot kg^{-1}$)	50.0	3.2	49.3 – 50.3
$30\text{-}15_{IFT}$ (HR peak) (bpm)	196.4	7.0	194.6 – 198.1
MSFT (VO_2max) ($ml \cdot min^{-1} \cdot kg^{-1}$)	51.2	4.1	10.2 – 52.3
2km Time Trial (s)	533	43	522 – 543
Average Aerobic Speed (AAS) (2km TT) ($m \cdot s^{-1}$)	3.8	0.3	3.7 – 3.9

Table 2. Multiple correlation summary of the deterministic model assuming $30\text{-}15_{IFT}$ (V_{IFT}) as a dependent variable. *

Model	$30\text{-}15_{IFT}$ performance (V_{IFT})	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	VO_2max#	.787	.620	.614	.574
2	AAS	.820	.672	.661	.538
3	SpMax	.846	.716	.702	.505
4	LMI	.858	.737	.718	.490

***Step = forward stepwise regression analysis; #Estimated VO_2max as per Buchheit (2008b); AAS = average aerobic speed (taken from 2 km time trial); LMI = Lean muscle Index**

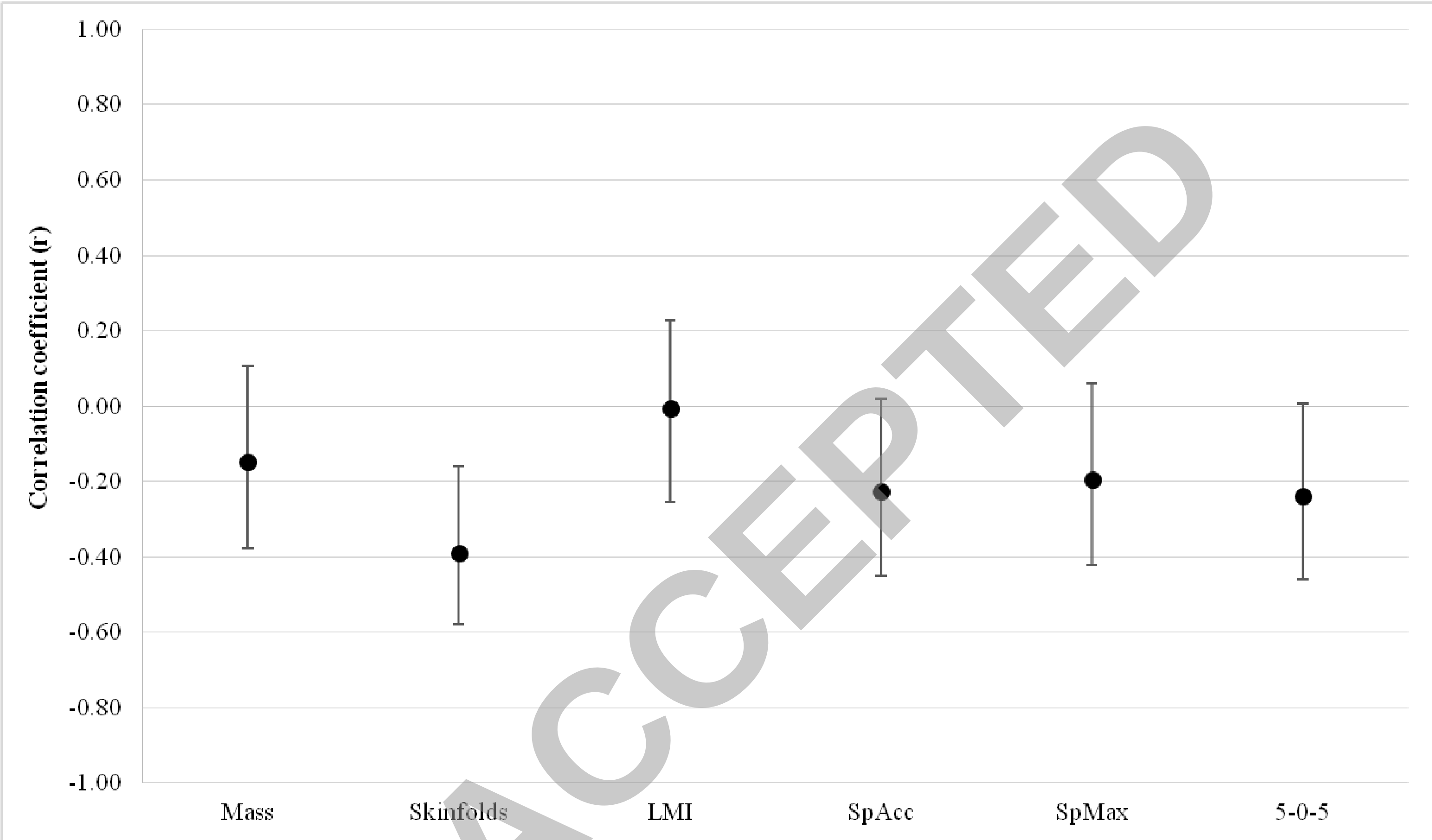

Figure 1. The correlations between V_{IFT} and various anthropometrical and physiological measures (mean +/- 95% CI) (LMI – Lean Mass Index).

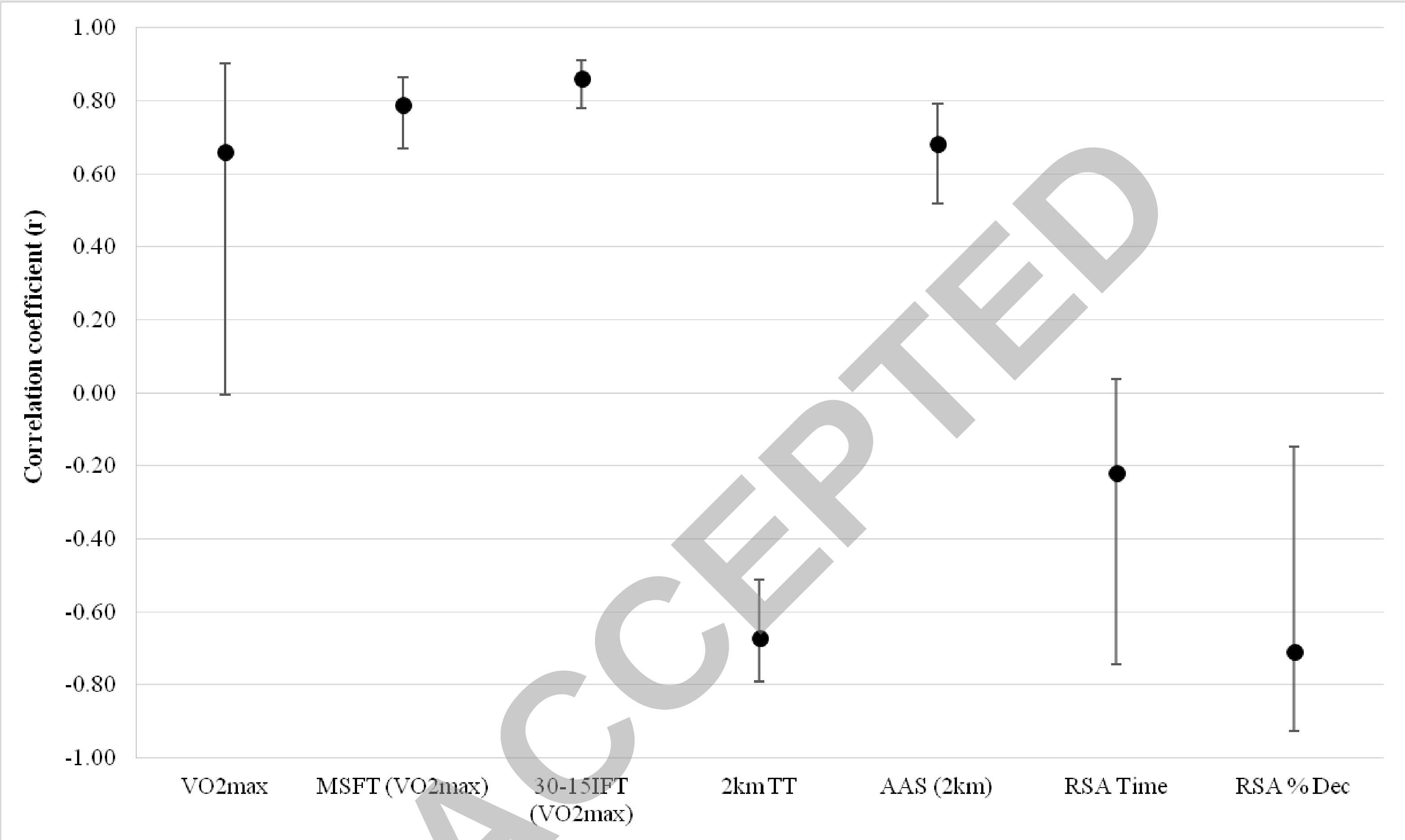

Figure 2. The correlations between V_{IFT} and various physiological measures (mean +/- 95% CI) (MSFT –Multi-Stage Fitness Test; AAS – Average Aerobic Speed; RSA –Repeat Speed Ability). * VO_2max and RSA tests (n=9).