A Brief Review of Methods to Quantify High-Speed Running in Rugby League: Are Current Methods Appropriate?

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Abstract:

High-speed running (HSR) has been documented within rugby league to differentiate playing standard, position and often precedes pivotal match events. Practitioners and researchers place importance on HSR due to its inclusion in assessing the demands of training and match-play to help prescribe accurate training loads and recovery methods. High-speed running can be quantified in absolute terms whereby the same threshold speed is applied to all players (e.g., $5.0\text{m}\cdot\text{s}^{-1}$). Within rugby league, differences in tactical demand, anthropometric and physical fitness characteristics exist between positions and players, suggesting that absolute HSR thresholds may not be appropriate due to under and over estimations of HSR data. Alternatively, practitioners may individualize the threshold speed to individual players physical qualities such as peak sprint speed, maximal aerobic speed (MAS) or the speed at which the ventilatory thresholds occur. Individualizing HSR warrants the practitioner to select a valid and practical test to quantify the HSR threshold speed. It is suggested that using peak sprint speed to quantify HSR can produce erroneous interpretation of HSR data whilst the practicality of specific physiological derived thresholds can be questioned. Implementing MAS to quantify HSR using a set time/distance trial may be the most appropriate approach for rugby league practitioners.

Key Words: Global Positioning Systems, Individualized, Maximal Aerobic Speed, Metabolic Power, Training Load

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INTRODUCTION

Rugby league is a collision-based team sport involving intermittent bouts of high intensity activities such as collisions, accelerations and high-speed running (HSR) (29). The game consists of two teams of 13 players, with each team having 4 bench players who can be interchanged throughout the course of match-play (29). The game comprises of two 40-minute halves separated by a 10-minute half time interval, with teams aiming to execute both offensive and defensive plays to outscore their opponents by placing the ball behind the opponents try line (29). The game is played globally at different playing standards (23), with professional teams being based predominantly in Australia (National Rugby League) and England (European Super League) as well as international teams competing in a world cup competition every four years.

Micro-electromechanical systems (MEMS) encompass gyroscopes, accelerometers, magnetometers and global position systems (GPS) (42). These systems have been used to monitor match and training physical activity metrics, such as HSR or high-intensity running (HIR), which often characterizes the positional demands of rugby league players (13, 20, 25). Rugby league players can be categorized into four positional groups, hit-up forwards (i.e., props), wide-running forwards (i.e., second row and loose forward), adjustables (i.e., hookers, halfbacks, and fullback) and outside backs (i.e., centers and wingers). Hit-up forwards tend to repeatedly accelerate over short distances in the middle of the field, whilst frequently being involved in ball carrying to assist in invading the opponent's half of the field (39). Wide-running forwards operate on the lateral areas of the field, allowing them to be involved in ball carrying and tackling in wider areas where it is less congested (39). Outside backs are often positioned in greater space and cover greater distances at high-speed due to kick return and kick chase activities (22). The adjustables positions are often associated with running at high-speed into open spaces whilst also supporting offensive plays (63). The HSR accumulated by players during match-play tends to be higher for outside backs (583m) and adjustables (436m) compared to hit-up forwards (235m) and wide-running forwards (418m) (25) due to outside backs and adjustables having greater space to accelerate into (>21m) and hit-up and wide-running forwards being involved in acceleration-based contacts over shorter distances (6-10m) (22, 57). Given the importance placed on HSR running metrics within rugby league, practitioners (e.g., technical/physical coaches and scientific support staff) often prescribe HSR in training (71, 73), whilst attempting to minimize the risk of injury occurrence (14, 49, 75). The measurement of HSR has become an important metric which can distinguish differences between playing standards and positions, as well as it often preceding pivotal match events (e.g., try scoring) (57).

Accordingly, the thresholds utilized to characterize HSR tend to be arbitrary and do not account for differences in anthropometric and physical fitness attributes amongst playing positions (57). Regardless of playing position, absolute thresholds in rugby league are based on one given speed (e.g., $5.0 m \cdot s^{-1}$ for HSR) which is applied to all players (50). Differences in anthropometric characteristics can characterize different playing positions (19, 47), with such discrete differences resulting in differences in tactical roles between positions (57). These differences represent hit-up forwards and wide-running forwards having generally heavier body mass than the outside backs and adjustables playing group (hit-up forwards: 106 ± 5.0kg; wide-running forwards: 99 ± 7.0kg; outside backs: 96 ± 4.0kg; adjustables: 86 ± 8.0kg) (20). Physical fitness characteristics establish outside backs have a faster 20m sprint time than the other playing groups (outside backs: 3.05s; adjustables: 3.09s; wide-running forwards: 3.10s; hit-up forwards: 3.13s) (19). Adjustables cover a greater distance than the other playing groups during a prone Yo-Yo Intermittent Recovery Level 1 (Yo-Yo IRL1) test, designed to assess rugby specific high-intensity intermittent running ability (adjustables: 987m; wide-running forwards: 979m; outside backs: 887m; hit-up forwards 834m) (18, 19). This likely implies it is more achievable for outside backs, adjustables and wide-running forwards to reach an arbitrary threshold in comparison to the hit-up forwards, resulting in greater HSR distances being accumulated for these positions. However, although differences in physical qualities exist between positional groups, differences will also be present between players within positional groups. For instance, two outside backs may have very different distances when completing the prone Yo-Yo IRL1 test, likewise two hit up forwards may have very different peak sprint speeds. The between position and between player differences that exist amongst players seemingly propose accurate training and recovery prescription could be inhibited (34, 57).

Individualized thresholds provide each player with a speed zone (see Appendix 1) often anchored to a physiological ‘landmark’ which may enhance the prescription of training loads and recovery methods on an individual basis (34, 57). Previous studies have implemented approaches to quantify HSR including the ventilatory thresholds (1, 34) and maximal aerobic speed (MAS) (21, 34, 42). Physical characteristics such as peak sprint speed have also been implemented (16, 24). Consequently, given the anthropometrical and physical playing positional differences between rugby league players (16, 20, 47), different HSR threshold approaches exist amongst team sports, questioning which one would be most appropriate for professional rugby league. Therefore, the purpose of this brief review is two-fold: 1) To identify the current absolute and individualized approaches and associated methods that exist in determining HSR thresholds and 2) establish which approaches are the most appropriate for their application within professional rugby league to quantify key match-play running activities.

ABSOLUTE THRESHOLDS

Absolute running threshold approaches enable practitioners to examine the locomotor profiles of player activity based on speed classification zones, with these zones differing amongst studies which have opted for this approach (2, 39, 63, 69). Practitioners may apply this approach to compare between-player and playing position physical outputs during training and match-play (71). However, despite its popularity amongst rugby league researchers (see Table 1.), variation in the absolute HSR threshold speed exists, with speeds ranging from $3.9 m·s^{-1}$ to $5.7 m·s^{-1}$ (2, 43, 67, 72). That said, these variations stem from modifications from original work conducted by Sirotic et al (58) who combined video analysis and computer-based tracking systems to analyze physical match-play activities within rugby league. However, McLellan et al (44) implemented MEMS devices within rugby league to quantify the absolute running speed zones by modifying previous zones generated for use within rugby union match-play . These zones proceeded to quantify the HSR threshold as $5.0 m·s^{-1}$, which has advanced to become the most applied speed within rugby league research (2, 25, 46, 63). Moreover, $5.0 m·s^{-1}$ may exceed individualized HSR threshold speeds, dependent on the individualized approach applied and the physical characteristics of players, suggesting that $5.0 m·s^{-1}$ may physiologically underestimate HSR distance for all playing positions. Consequently, this likely infers that absolute thresholds within rugby league research are inconsistent (32). Currently, it is unknown which absolute HSR threshold is favored amongst practitioners, with GPS manufacturer's default thresholds being an option for practitioners or alternatively applying an absolute threshold reported in published research.

Despite the broad utilization of HSR thresholds amongst rugby league practitioners and researchers, large differences in body-mass between playing position are present amongst European Super League players (hit-up forwards: 106 ± 5.0kg; wide-running forwards: 99 ± 7.0kg; outside backs: 96 ± 4.0kg; adjustables: 86 ± 8.0kg) (20). This likely contributes to the interpretation and practical usability of the data collected. For instance, an absolute threshold ($5.0 m \cdot s^{-1}$) being applied for players at either end of the this body-mass continuum could be suggested as inappropriate, with heavier players having reduced ability to achieve the set speed and lighter players having increased ability to do so (57). If prescribed HSR loads are not achieved within training, heavier players (likely 'hit-up forwards') maybe required to participate in HSR specific drills to achieve the desired training stimulus, therefore unachievable thresholds may inhibit the effectiveness of recovery and athletic development strategies. However, further research is required to formalize such theory.

In rugby league, it is likely that a heavier player may have a lower peak speed, whereas a lighter player may have a higher peak speed (22). Hypothetically, applying an absolute running speed threshold of $5.0 m \cdot s^{-1}$ could result in a hit-up forward (likely heavier) with a peak speed of $8.0 m \cdot s^{-1}$ needing to achieve 63% of their peak speed to register HSR, whereas an outside back (lighter) with a peak speed of $9.5 m \cdot s^{-1}$ only needing to achieve 53%. Therefore, it could be suggested that the application of an absolute high-speed threshold can actually underestimate HSR for players with lower peak speeds and overestimate HSR for players with higher peak speeds (57). Subsequent misinterpretation may lead to incorrect training load monitoring and recovery prescription (57). Nonetheless, practitioners may implement an absolute threshold if their players physical qualities are more uniformed whereby the absolute HSR threshold applied represents the included players MAS (15), therefore demonstrating a greater relative contribution will have been interpreted. Consequently, practitioners should bear in mind the aforementioned considerations for absolute thresholds when selecting a method to measure HSR within rugby league (Figure. 2).

******** Table 1 about here ********

INDIVIDUALIZED THRESHOLDS

The integration of player characteristics to individualize HSR formalizes an individual specific locomotor profile (42). Applying an individualized threshold may provide alternative analysis of a player's running performance, as it identifies the point at which the player's movement speed exceeds a previously determined physiological/physical threshold that is classified as high-speed, particularly when its determined based on individual physical qualities (e.g., % of peak sprint speed) (16) (see Appendix 1). Additionally, an alternative evaluation of external load is generated which likely enables practitioners to prescribe individual training loads and recovery methods, (10, 54, 57). Individualized speed threshold approaches are often anchored to player speed and fitness properties, whereby a theoretical framework is utilized to better evaluate training and game demands, in an attempt to maximize player fitness (42). For instance, the highly variable reported range of absolute speeds to determine HSR, may in fact include the relative speeds at which physiological transitions occur within moderate-heavy and heavy-severe intensity domains, which can distinguish the difference between different locomotor categories (57). Although individualized approaches exist amongst rugby league literature (see Table 2.), their popularity amongst rugby league practitioners is unknown. Nonetheless, given the obvious between playing position differences in anthropometric and physical fitness characteristics, it could be inferred that application of individualized approaches to HSR, (such as peak sprint speed, MAS or implementing a method to quantify the speed upon entering the heavy intensity domain) is of practical relevance and importance to rugby league practitioners to enhance training prescription, load management and recovery strategies (Figure 2).

PEAK SPRINT SPEED DERIVED THRESHOLDS

Practitioners may apply an individualized locomotor profile which is normalized to the individuals peak sprint speed to help compare relative intensities amongst players (16). Standardizing the HSR threshold as a percentage of the individual peak sprint speed (see Appendix 1) maybe considered a more justified approach due to increasing the HSR attributed to slower players and reducing the HSR attributed to faster players (24, 50). To apply the percentage, practitioners would likely instruct players to perform a linear peak sprint speed test, often using a timed maximal sprint assessment over a distance of 30-40 m using either a dual beam timing gates (16, 24) or radar gun (42). However, during rugby league match-play only 17% of the total sprints are between 30m and 40m with the most common between 6m and 20m (22). Therefore, questioning the practical relevance of using speeds achieved at distances greater than 20m to individualize HSR. Moreover, due to small bias and errors associated between testing methods, it is advisable for practitioners to implement the same method longitudinally (55) and avoid validity issues when inferring a threshold speed to GPS devices from an alternative method.

Peak sprint speed could also be identified from GPS derived time-motion analysis data collected during training and matches (10, 50). However, these speeds tend to be lower than those derived from digital timing gates (GPS: 7.7m·s^{-1}, 40 m Sprint using Timing Gates: 9.1m·s^{-1}) (22) due to peak sprint speed during match-play being determined by tactical and positional demands (10). Implementing 10 HZ GPS to assess peak speed during a 40 m sprint has been validated within rugby union, whereby practitioners use the same GPS unit and software for each player (55) to capture players peak running speeds. Therefore, it may be more appropriate to determine peak speed using GPS during rugby specific speed training. Dempsey et al (16) examined differences in match demands between junior and senior international rugby league players using the individual peak sprint speed approach to HIR, with the threshold set at 65%. The findings reported backs covered more distance at high-intensity than forwards both at senior (358 ± 204m v 253 ± 164m) and junior level (279 ± 112m v 246 m ±181m). This approach helped compare relative intensities and suggested that backs accumulate greater HIR due to on-field position, with defenses being less compact out wide, allowing backs to achieve greater running speeds (16). Similarly, Gabbett et al (24) also monitored junior rugby league players however, the HSR threshold was set at 50% of peak sprint speed (34, 56). Players were grouped according to chronological playing age and standard, with mean threshold speeds increasing with advancing age and were greater within the age groups if playing standard was higher. However, it was speculated that two players could perform the same amount of absolute HSR but due to differences in peak sprint speed, the slower player accumulates greater relative stress, consequently inhibiting training prescription and recovery requirements of individual players. Implementing both absolute and relative terms may better examine the demands of competition (24), although this could overcomplicate analysis and suggest to proceed with just the one approach longitudinally.

In addition to rugby league, other team sports (e.g., soccer, hockey, Australian rules football, rugby union) have implemented peak sprint speed to determine HSR (10, 34, 50, 56). Hunter et al (34) applied 50% of peak sprint speed to determine HSR during 22 academy soccer matches. This study suggested using peak sprint speed would be inappropriate in both the applied and research settings due to meaningful interpretation errors in HSR data. In addition, Scott and Lovell (56) also applied 50% of peak sprint speed (range: 3.7m·s^{-1} – 4.7m·s^{-1}) to examine if it enhanced the internal dose-response. Their findings identified that the peak sprint speed approach had an impaired ability to determine the internal dose response of the player and supported previous findings which result in interpretation errors due to under and over-estimations of HSR (24, 34). However, Murray et al (50) applied 55% of peak sprint speed (4.5 m·s^{-1}) within professional Australian rules football and reported slower players with higher relative chronic high-speed running loads, resulted in a practically decreased likelihood of injury (93% likely) when compared to lower chronic loads (50). This may suggest that an individualized approach to threshold prescription may have a protective effect for injury occurring suggesting that practitioners should consider the running demands of each individual player (50). Consequently, differences in the threshold percentage exist amongst studies, suggesting the application of this individualized speed threshold approach to be questionable. Additionally, applying the same HSR threshold percentage to all players is somewhat arbitrary and HSR would be still affected by the issues already alluded with absolute HSR threshold approaches.

For example, applying a 65% threshold, player A is an outside back with a peak speed of 9.5m·s^{-1} and a HSR threshold of 6.2m·s^{-1}, whereas player B is a wide-running forward with a peak speed of 8.4m·s^{-1} and a HSR threshold of 5.5m·s^{-1} (Figure 1). However, players B's intermittent fitness is greater than player A's which is demonstrated by the greater intermittent fitness test score in Figure 2, allowing player B to enter their HSR zone more frequently and aiding in an accelerated recovery process (34). Moreover, it could be proposed that two players have the same peak sprint speeds and therefore the same threshold speeds, but a difference in aerobic fitness (5) can result in contrasting performances. This suggests the more aerobically fit player has an increased running economy enabling them to recover more quickly between bouts and accumulate greater HSR distance (36). These considerations compel individualizing HSR using this approach more complex, especially if variations in physiological qualities are apparent amongst rugby league players.

******** Figure 1 about here ********

PHYSIOLOGICAL DERIVED THRESHOLDS

Practitioners may consider fitness-based approaches to quantify HSR with them stemming from sound physiological rationale. These approaches apply the individual speed which materialized at the same time point in which a subsequent physiological transition occurred (34) (see Appendix 1). Implementing a fitness-based approach to determine HSR may not only provide an individualized approach to training prescription and match analysis, but could potentially give the practitioner an insight into distance and time spent above a physiological threshold (21). Therefore, it is important for practitioners to consider which is the most appropriate approach to take to ensure the chosen physiological test is suitable and can be practically scheduled within a professional rugby league training timetable (42) (Figure 2).

**********Schematic of Figure 2 presented here**********

LABORATORY BASED THRESHOLDS

A potential approach to identify accurate running speed thresholds is for rugby league practitioners to base HSR thresholds on objective physiological measures which represent the transition from the moderate to the heavy intensity domain such as the 2nd ventilatory threshold (VT^2) (1, 34). This threshold is identified as the speed which corresponds to the inflection in the ventilatory equivalents for both oxygen and carbon dioxide, whilst a corresponding reduction in the end tidal partial pressure of carbon dioxide also occurs (34). The traditional method for quantifying VT^2 would be for players to complete an incremental laboratory-based test until exhaustion. Hunter et al (34) proposed deriving VT^2 speeds using laboratory-based assessments better represent the dose-response relationship due to representation of changes amongst running intensity domains (61). However, the ecological validity of linear, continuous, incremental (exhaustive) treadmill tests to test players participating within multi-directional, intermittent team-sports is questionable , coupled with the requirement for systematic re-testing and a finite number of opportunities to schedule testing during the in-season period (57). Furthermore, only one player at a time can be tested proposing that this approach is not feasible within a typical squad (~20) players. The requirement to retest proposes high cost relating to specialized equipment and expertise needed for this to be conducted effectively and frequently. Confirmation of these complexities acting as a barrier for implementing this method are currently unknown and further research examining practitioners' perspectives on the situational and environmental factors that influence their decision making is required. Consequently, only one rugby league study has used this approach for threshold determination, however this was a case study design using one participant (61).

Despite the complexities, other team sports such as soccer have applied this approach to individualize HIR during professional soccer matches (1). The VT^2 approach applied by Abt and Lovell (1) quantified HIR using the laboratory based incremental treadmill test. The resulting thresholds ($4.0 m \cdot s^{-1}$ – $4.6 m \cdot s^{-1}$) were applied to match-play data to calculate individualized HIR, showing that less aerobically fit players (lower VT^2 speeds) performed greater HIR distances than the more aerobically fit players (higher VT^2 speeds) ($r = -0.68$). A proposed reasoning was not included, however differences in positional anthropometric, physical fitness and match demands could have contributed (10, 57). Players with lower speeds at VT^2 with increased HIR match demands would have a lower threshold speed to achieve HIR, whereas players with higher speeds at VT^2 and lower HIR match demands would have a higher threshold speed to achieve HIR. This could result in implications for both the practitioner and players when prescribing individualized recovery methods and training prescription based on variations existing amongst physiological qualities and HIR demand between position. However, it is not known whether implementing this evidence-based approach would enhance training and performance within rugby league. Therefore, it could be suggested that future research is directed towards investigating the speed at VT^2 derived from a laboratory-based assessment to individualize HSR in rugby league.

FIELD BASED THRESHOLDS

Previous suggestions express specific field-based assessments can also produce an estimation as to the speed at which the transition from the moderate to the heavy intensity domain occurs. The 30:15 Intermittent Fitness Test (30:15IFT) is an incremental and intermittent test requiring players to work for 30s and recover for 15s. Players perform shuttle runs between two 40 m lines starting at a speed of $8 km \cdot h^{-1}$, which increases $0.5 km \cdot h^{-1}$ after every 45s stage (7). A recent study by Scott et al (57) incorporated the 30:15IFT to individualize HSR thresholds amongst professional rugby league players (7). The players completed the 30:15IFT to estimate the velocity of the last completed stage within the test which was applied to previous work by Buchheit et al (8), whereby the estimated velocity achieved at VT^2 was generated as 87% of the final velocity (see Appendix 1). It was suggested that this may provide practitioners with a greater insight into a players running load and is more practical than a laboratory-based assessment (57) (Figure 2). This method may allow practitioners to prescribe training loads and implement recovery strategies more precisely.

The 30:15IFT has also been prescribed to determine the speed achieved at the 1st ventilatory threshold (VT^1) within rugby league, with this speed calculated as 68% of the final velocity (8, 57) and applied as the HSR threshold (11) (see Appendix 1). The findings suggest exposing players to greater HSR loads during the pre-season period may contribute to maximizing high-speed activities within competitive matches (11). Furthermore, this field-based test includes a change of direction (subsequent metabolic cost) and is intermittent in nature which better represents the demands of team sport and enhances the ecological validity. It is also suggested that the 30:15IFT can help to prescribe different formats of conditioning (7). However, the proposed individualized VT^1 and VT^2 methods established by Scott et al (57) can be considered somewhat contradictory, due to quantifying HSR by applying an arbitrary percentage to the final stage velocity of the 30:15IFT for all players. Moreover, the arbitrary percentages established within this study, where derived as an average from an unrelated group of soccer, handball and basketball players (8). This could result in misinterpretations in subsequent HSR data for rugby league players due to the differences in physical qualities amongst players. Furthermore, the frequent retesting and exhaustive nature of the test may likely interfere with training sessions dedicated to recovery and match preparation strategies (Figure 2). For instance, match frequency within rugby league varies between 3 and 9 days, whereby longer rest periods elicit higher training loads and shorter rest periods intensify the training schedule resulting in practitioners reducing training loads and focusing on recovery processes (62, 75). Consequently, practitioners may consider alternative approaches to quantifying HSR which implement the associated internal responses during continuous running tests which may be deemed more appropriate (Figure 2).

HEART RATE DEFLECTION POINT

In addition to the speed at VT^2, there are internal responses which concurrently onset such as the heart rate deflection point (56). The deflection point is defined as the downward or upward change from the linear heart rate/load relationship which is evident during incremental exercise testing and is heavily associated to VT^2 and the transition from moderate to heavy intensity domains (56). Although likely identified during laboratory-based testing (34, 56, 57), it can also be identified during continuous running field-based assessments (56). Using a modified version of the University of Montreal Track test (40, 48) (see Scott and Lovell et al (56) for full methods), the VAM-EVAL (48, 56) test which is an incremental and continuous running test (to exhaustion) has been used to identify the heart rate deflection. This approach has been used within women's international soccer and identified HSR as the speed at which the heart rate deflection point occurs. The heart rate deflection point occurred on average at 82% of the final running speed however, applying 80% of the final running speed has previously been shown to determine HSR incorrectly (34). Although the VAM-EVAL has been used to determine the heart rate deflection point, this method failed to identify this for 23% of the initial player sample (56). Accordingly, it could be suggested that attempting to implement the speed at which the heart rate deflection point occurs during a field-based test may not be the most valid approach to quantifying HSR in rugby league players (Figure 2).

MAXIMAL AEROBIC SPEED

The identification of MAS has become more apparent within team sports, likely due to it being a more practical, field-based test that can be implemented at a training facility without specialized equipment (5). Determination of MAS allows practitioners to install an alternative method for measuring running performance and maximizing fitness, whilst generating a simple and effective way of prescribing formats of conditioning (3, 21). Typically, MAS is defined as the lowest running speed ($m \cdot s^{-1}$) at which $\dot{V}O_{2\,max}$ occurs (5) and it can be suggested that MAS is a well-defined physiological parameter that may be a suitable tool for identifying relative exercise intensity (48). It is well documented that aerobic capacity is a crucial property of rugby league players (3, 47), suggesting that MAS may be implemented to determine HSR thresholds within rugby league (Figure 2).

It is evident MAS has been utilized differently within the literature to identify transitions in intensity domains. The true MAS speed (100% MAS) may be modified to determine HSR, whereby 100% MAS may be applied or a higher or lower percentage may be considered (21, 34, 54) (see Appendix 1) although 80% of MAS has been suggested to quantify HSR erroneously (34). Currently only one rugby league study implements MAS to quantify HIR, with 75% of the MAS derived from the Multi-Stage Fitness Test (MSFT) applied as the HIR threshold amongst selected and non-selected junior players (70). Alternatively, MAS may be interpreted with its association to peak sprint speed and the resulting anaerobic speed reserve which is the difference in speed between MAS and the peak sprint speed (54). This approach was conducted by Mendez-Villanueva et al (48), who applied MAS as the HSR threshold and identified the anaerobic speed reserve to better establish a player's transition from HSR into sprinting. Furthermore, it has been suggested that using MAS, in combination with peak sprint speed and the anaerobic speed reserve is a more ecologically valid approach (21). This is due to normalizing players speed thresholds with sprinting capacity, based on players achieving a high percentage of their peak sprint speed during match play (21, 34). However, this approach is yet to be applied within rugby league.

For the practitioner, it is worth considering which field-based test is deemed the most appropriate to practically determine MAS. A range of field-based tests can determine MAS (see Appendix 1 and Figure 2), and when working with a full squad of players (~30-40) it is warranted for practitioners to select a valid and reliable test which does not impede other aspects of training and potentially inhibit performance (57). It is also worth considering the appropriateness of the tests available as they can be categorized as continuous, linear (Time Trial, Set Distance Trial) or shuttle based (Multi-Stage Fitness Test (41), 1200m Shuttle Test (35)) as well as continuous, incremental

(Montreal Track Test (40), VAM-EVAL (9)), or even intermittent and incremental in nature (Yo-Yo IRL1 (56), 30:15IFT (7)). It could be argued that shuttle-based tests maybe more rugby league specific, especially if they are intermittent in nature. However, shuttle field-based tests may estimate MAS inaccurately, due to not being continuous in nature and causing greater metabolic cost due to the inclusion of accelerations and decelerations. Previous work by Berthoin et al (4) corroborates this with the Multi-Stage Fitness Test underestimating MAS (13.1 ± 1.0km·h^{-1}) when compared to the University of Montreal Track Test (15.8 ± 1.9km·h^{-1}) and the incremental treadmill test (15.9 ± 2.6km·h^{-1}) suggesting accelerations, decelerations, stops, turns and starts constrain running rhythms as speed increases. This could deem these tests questionable, as a corrective equation is usually applied to estimate MAS (4), perhaps raising doubt over its practical relevance for use within rugby league.

Continuous and incremental tests (9) could be deemed more appropriate for MAS determination then those previously mentioned. However, these tests along with some shuttle-based tests may prove difficult to frequently periodize within a rugby league training schedule. Nevertheless, it could be suggested that a set time trial or a set distance trial such as a 5-minute run, or a 1.5km time trial, could be a more appropriate test for rugby league application due to their practicality and simplification to determine MAS, albeit linear and continuous (5, 21) (see Appendix 1 and Figure 2). That said, individualizing HSR by applying a physiological threshold could be considered by rugby league practitioners, although due to validity and practicality implications amongst approaches, it could be proposed that quantifying HSR using MAS derived from a set time trial may be the most appropriate physiological threshold for rugby league practitioners. However, individualized speed thresholds do not consider the transition between zones in the form of acceleration and focus on speed alone (57). Alternatively, metabolic power combines both speed and acceleration properties which if individualized, may be suggested to be more applicable for quantifying HSR in rugby league.

METABOLIC POWER THRESHOLDS

Rugby league running performance combines both speed and acceleration properties which elicits an associated metabolic cost (W·kg^{-1}) (38). The metabolic cost of accelerations is generally greater than the cost of running at a constant speed. While high-intensity accelerations can occur during lower speeds whereby the metabolic cost is high (38), both absolute and individualized speed zones do not consider this. A recent approach proposed that accelerating on a flat surface is metabolically equivalent to running on an incline at a constant speed (17, 51). The resultant equivalent slope can be implemented to estimate the energetic cost of exercise, and specifically for team sports, practitioners can quantify the distance accumulated within different metabolic power zones (39). Moreover, recent developments by Gray et al (30) have established an alternative energy-based approach which can quantify metabolic power by calculating the mechanical work performed to accelerate an individual's center of mass horizontally, vertically, to overcome air resistance and to swing the limbs (30, 31). These approaches may be applied to determine a high-power threshold and subsequently quantify the distance covered at high-power. This may allow practitioners to better understand the running demands of rugby league match-play, due to providing a better reference for metabolic load (57) by combining the cost of both speed and acceleration, rather than just focusing on HSR derived from speed zones (39).

ABSOLUTE METABOLIC POWER THRESHOLDS

Studies incorporating high-power distance using metabolic power currently exist within rugby league research (12, 15, 39, 59). However, the majority of these studies quantify this using an arbitrary threshold ranging between 18W·kg^{-1}-20W·kg^{-1}. Kempton et al (38), applied 20W·kg^{-1} and identified both high-power distance and HSR resulted in similar reductions throughout match-play, despite high-power distance demonstrating greater values. Other studies using this threshold have also reported high-power distance to be higher than absolute HSR distance and have suggested HSR underestimates the running demand of rugby league when compared to high-power (39, 72). Although 20W·kg^{-1} is the more profound threshold within the literature, Cummins et al, (15) applied a threshold of 18W·kg^{-1} and established that the metabolic demands of match-play differ between interchange and full match players as well amongst position (12). Alike HSR thresholds, players work capacities, anthropometric characteristics and positional demands vary, proposing the metabolic cost of running will vary for individual players, suggesting that deriving high-power using an arbitrary threshold may misinterpret the relative stress imposed on players (53, 57).

INDIVIDUALIZED METABOLIC POWER THRESHOLDS

Consequently, Scott et al (57) proposed to individualize high-power within rugby league and quantified the thresholds by manipulating the 30:15IFT. The threshold was derived by inputting the speed at 87% of the final velocity achieved into the metabolic power calculation (adjustables: 22.0 ±0.7 $W{\cdot}kg^{-1}$; outside backs 21.1 ± 1.5$W{\cdot}kg^{-1}$; wide-running forwards 21.7 ± 0. 5$W{\cdot}kg^{-1}$; hit-up forwards 21.0 ± 0. 5$W{\cdot}kg^{-1}$) and distances were then compared with distances above 20 $W{\cdot}kg^{-1.}$ Relative high-power distances were lower when compared to absolute distances (adjustables: 1137 ± 324m v 1315 ± 373m; outside backs: 1377 ± 189m v 1468 ± 216m; wide-running forwards: 1296 ± 109m v 1486 ± 118m; hit-up forwards: 797 ± 175m v 851 ± 204), and absolute high-power thresholds may overestimate high metabolic running performance dependent on position. For players with lower levels of fitness, absolute high-power thresholds may underestimate high metabolic running performance (57). However, although this approach is considered as individualized, it estimates metabolic power by implementing an arbitrary percentage of the final velocity achieved during the 30:15IFT. This could be considered contradictory with the inclusion of an arbitrary percentage and implementing a method that quantifies individualized metabolic power may be more appropriate.

Research within hockey by Polglaze et al (53) has integrated critical power which is defined as the boundary between steady state and non-steady state exercise (64). This concept proposes individuals can exercise indefinitely below their critical power threshold but when above the threshold, only a fixed amount of work (finite work capacity) can be performed (64). When this concept is applied to power output, work performed below the critical power threshold is measured in watts and the finite work capacity above this is measured in kilojoules (64). Whereas, when applied to velocity, work performed below the critical velocity threshold is measured in $m{\cdot}s^{-1}$ and the finite work capacity is measured in meters (64). It has previously been suggested that parameters derived from this power/velocity-time relationship can be used to describe a 'gold standard' demarcation of the metabolic steady state and the finite work capacity of individuals (64, 66).

Accordingly, with rugby league being intermittent in nature, the power output at critical power, will be lower than traditional exercise modalities which incorporate continuous exercise (53). Therefore, Polglaze et al (53) proposed the use of a 3-minute all-out hockey specific field-based test to quantify the metabolic power at critical power, as this may provide a more appropriate and comprehensive assessment. The mean metabolic power over the last 30s of the tests was quantified as the high-power threshold (10.5W·kg^{-1}), which is considerably lower than the absolute and relative high-power thresholds previously mentioned within rugby league. However, the power thresholds within these studies have equated to estimations of physiological landmarks such as VT^2 and $\dot{V}O_{2max}$ which constitute greater physiological thresholds (53) and these thresholds may be excessive leading to underestimations in the amount of high-intensity work performed in team sports (53). This study further suggested that the critical metabolic power approach is more appropriate to classifying intensity, which incorporates continual changes in speed and direction and deemed it useful for team sport practitioners (53). However, this study implemented the metabolic power model originally established by di Prampero et al (17, 51) which can estimate the metabolic demand of forward propulsion but cannot quantify the energetics of team sports in their entirety (31). Due to this, it may be worth practitioners considering the recent approach by Gray et al (30) to help estimate the metabolic power at critical power by more accurately quantifying the work performed during intermittent field-based sports, based on the principles of the work-energy theorem (30, 31).

It could be proposed that the critical power approach may be more appropriate for quantifying the high-power running activity within rugby league, although a 3-minute all-out rugby league specific field-based test is currently undefined, and practitioners may consider this approach if a test is established.

******** Table 2 about here ********

CONCLUSION

Current research highlights different approaches to quantifying HSR although it does not consider how appropriate specific approaches and testing procedures are for administering within a professional rugby league training and match schedule. Based on the evidence within this brief review, it is proposed that the absolute threshold approaches to quantifying HSR within rugby league are not appropriate. This is due to the likely under and over estimations of HSR data dependent on differences in individual player physical qualities (19, 47). Individualized approaches such as peak sprint speed can produce erroneous interpretations, whilst the practicality and arbitrary nature of specific physiological derived thresholds might be questioned. Therefore, we recommend that practitioners should consider applying MAS methods to quantify HSR using a set time and/or distance trial (e.g., 1500m time trial, 5-minute run) to accurately prescribe HSR thresholds which are able to account for between playing position differences in anthropometric (19, 20) and physical fitness qualities (19, 47) of professional rugby league players. This approach stems from sound physiological rationale and can be practically administered amongst a rugby league squad during normal training practices (Figure 2).

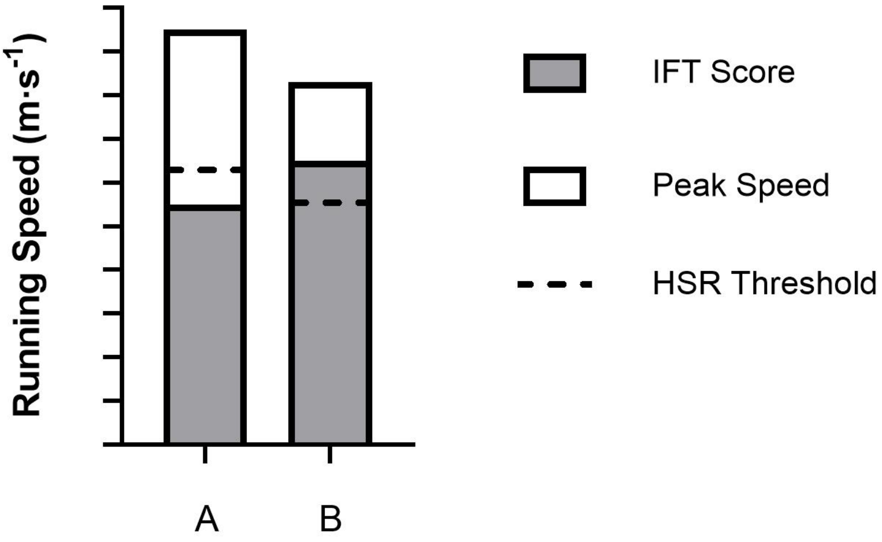
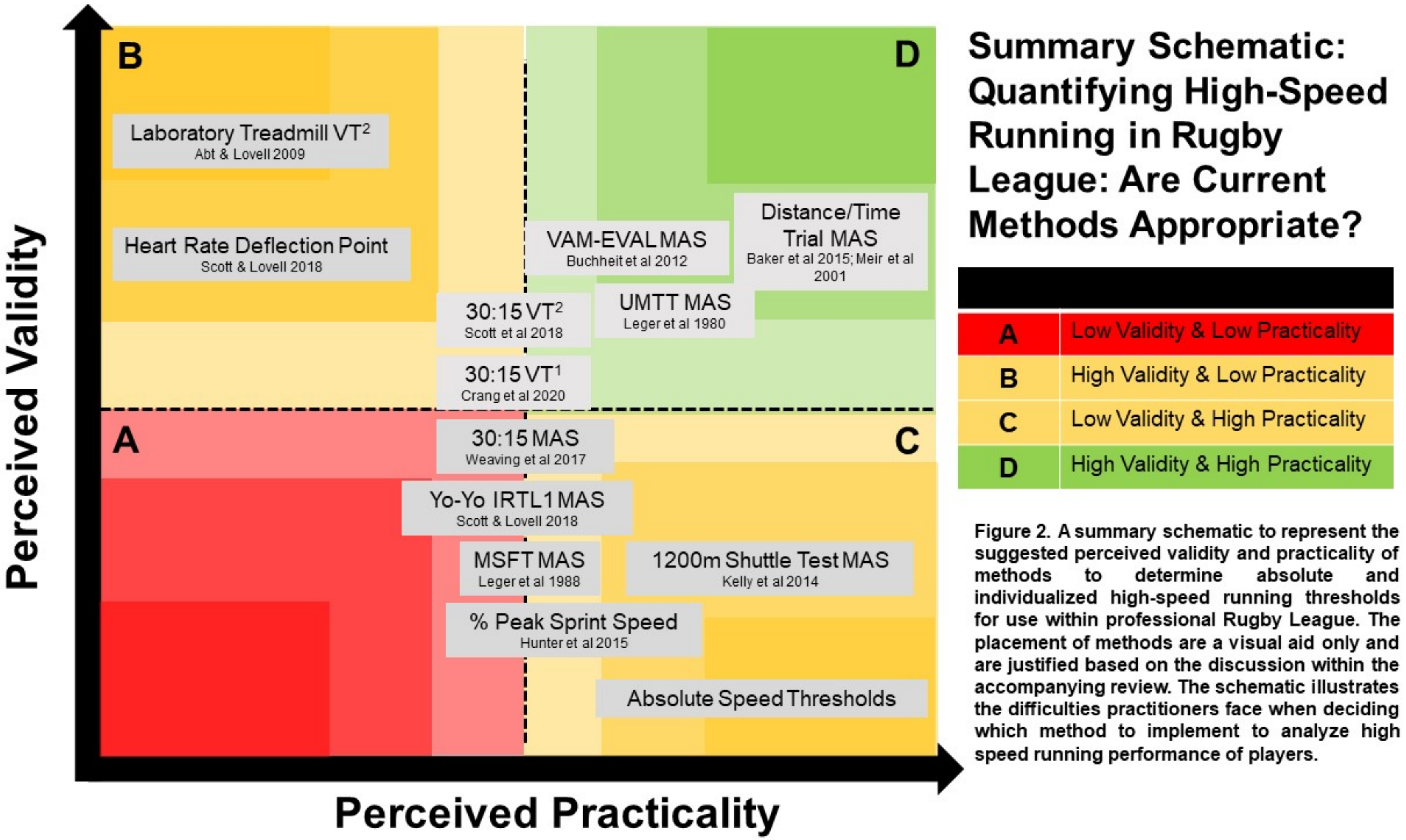


Figure 1. Demonstration of how the use of peak speed to derive HSR can result in erroneous interpretations for Player A and Player B. Intermittent Fitness Test Speed is the final stage speed achieved during a ‘hypothetical’ intermittent fitness test.



A	Low Validity & Low Practicality
B	High Validity & Low Practicality
C	Low Validity & High Practicality
D	High Validity & High Practicality

Figure 2. A summary schematic to represent the suggested perceived validity and practicality of methods to determine absolute and individualized high-speed running thresholds for use within professional Rugby League. The placement of methods are a visual aid only and are justified based on the discussion within the accompanying review. The schematic illustrates the difficulties practitioners face when deciding which method to implement to analyze high speed running performance of players.

Figure 2. A summary schematic to represent the suggested perceived validity and practicality of methods to determine absolute and individualized high-speed running thresholds for use within professional Rugby League. The placement of methods are a visual aid only and are justified based on the discussion within

the accompanying review. The schematic illustrates the difficulties practitioners face when deciding which method to implement to analyze high-speed running performance of players.

Table 1. Rugby League studies using GPS and absolute thresholds to quantify HSR.

Study	Absolute HSR Thresholds
Weaving et al (72)	3.9 $m \cdot s^{-1}$
Waldron et al (69),(67), Thornton et al (60)	4.0 $m \cdot s^{-1}$
Kempton et al (38), (39), Kempton & Coutts ,(36), Waldron et al (68)	4.1 $m \cdot s^{-1}$
Kempton et al (37), Weaving et al (73), Cummins et al (13)	4.3 $m \cdot s^{-1}$
McLellan et al (44), (45), (46), Gabbett (22), (23), (24), Gabbett et al (25), (27), (26), Gabbett & Ullah (28), Austin & Kelly (2), Murray et al (49), Twist et al (63), Black & Gabbett (6), Evans et al (20), Hulin et al (33), Cummins et al (12), (15), Oxendale et al (52), Thornton et al (59), Windt et al (75), Weaving et al (74)	5.0 $m \cdot s^{-1}$
Scott et al (57)	5.2 $m \cdot s^{-1}$
Varley et al (65), Twist et al (62)	5.5 $m \cdot s^{-1}$
Cummins et al (14), Mclean et al (43)	5.7 $m \cdot s^{-1}$

Key: High-speed running (HSR); Meters per second ($m \cdot s^{-1}$)

Table 2. Rugby League studies using GPS and relative threshold approaches to quantify HSR.

Study	**Player Status**	**Country**	**Competition**	**HSR Threshold Method**	**Test**
Dempsey et al (16)	Elite & Junior	England	INT	65% Peak Sprint Speed	40m Sprint
Scott et al (57)	Elite	Australia	NRL	87% Final Velocity	30:15IFT
Crang et al (11)	Elite	Australia	NRL	68% Final Velocity	30:15IFT
Weaving et al (71)	Semi-Professional	England	KPC	100% Final Velocity	30:15IFT
Towlson et al (61)	Semi-Professional	England	KPC	VT^2 Speed	Incremental Treadmill Test
Waldron et al (70)	Junior	England	N/A	75% Final Velocity	MSFT
Gabbett (24)	Junior	Australia	N/A	50% Peak Sprint Speed	40m Sprint

Key: High-speed Running (HSR); Ventilatory Threshold 2 (VT^2); 30:15 Intermittent Fitness Test (30:15IFT); Multi-Stage Fitness Test (MSFT); National Rugby League (NRL); International (INT); Kingstone Press Championship (KPC)

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