**Manuscript Title**: The concurrent validity of a rugby-specific Yo-Yo Intermittent Recovery Test (Level 1) for assessing match-related running performance.

**ABSTRACT**

This study investigated the concurrent validity of a rugby-specific high-intensity intermittent running test (HIIR) against the internal, external and perceptual responses to simulated match-play. Thirty-six rugby league players (age 18.5 ± 1.8 years; stature 181.4 ± 7.6 cm; body mass 83.5 ± 9.8 kg) completed the prone Yo-Yo IR1, of which sixteen also completed the Yo-Yo IR1, and 2 x ~20 min bouts of a simulated match-play (RLMSP-i). *Most likely* reductions in relative total, low-speed and high-speed distance, mean speed and time above 20 $W \cdot kg^{-1}$ (HMP) were observed between bouts of the RLMSP-i. Likewise, rating of perceived exertion (RPE) and percentage of peak heart rate ($\%HR_{peak}$) were *very likely* and *likely* higher during the second bout. Pearson's correlations revealed a *large* relationship for the change in relative distance ($r$ = 0.57-0.61) between bouts with both Yo-Yo IR1 tests. The prone Yo-Yo IR1 was more strongly related to the RLMSP-i for change in repeated sprint speed ($r$ = 0.78 *cf.* 0.56), mean speed ($r$ = 0.64 *cf.* 0.36), HMP ($r$ = 0.48 *cf.* 0.25), fatigue index ($r$ = 0.71 *cf.* 0.63), $\%HR_{peak}$ ($r$ = -0.56 *cf.* -0.35), $RPE_{bout1}$ ($r$ = -0.44 *cf.* -0.14), and $RPE_{bout2}$ ($r$ = -0.68 *cf.* -0.41) than the Yo-Yo IR1, but not for blood lactate concentration ($r$ = -0.20 to -0.28 *cf.* -0.35 to -0.49). The relationships between prone Yo-Yo IR1 distance and measure of load during the RLMSP-i suggests it possesses concurrent validity and is more strongly associated with measures of training or match load than the Yo-Yo IR1 using rugby league players.

**Keywords:** Aerobic capacity, acceleration, change of direction, collision, team sport.

## INTRODUCTION

Objective evaluation of rugby league players' physical qualities enables practitioners to monitor individual development and assess the effectiveness of training programmes (10). The assessment of high-intensity intermittent running (HIIR) capacity, referring to one's ability to repeatedly perform intense exercise and recover (23), is of interest given its contribution to repeated high-intensity efforts (i.e. number of tackles) and the team's scoring and defensive capabilities (8). High-intensity intermittent running is also reported to influence post-match recovery (20), injury risk (7), and is a key indicator for talent identification programmes (10).

Field-based tests such as the Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) (23) and 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$) (5) are often used to assess HIIR capacity in rugby league players (1,27). Performance in these tests is defined as the total distance covered or peak running speed attained, both of which show strong associations with maximal oxygen uptake ($\dot{V}O_{2max}$) (7,26). However, as players with a similar $\dot{V}O_{2max}$ can achieve a peak distance or velocity during these tests that differs by ~1000 m (23) or 4 $km \cdot h^{-1}$ (5), it is clear HIIR has several physiological determinants. Indeed, Scott et al. (26) recently demonstrated that $\dot{V}O_{2max}$ determined by a multistage fitness test, mean speed during a 2000 m time trial and peak velocity over 40 m accounted for 70.2% of variance in $30\text{-}15_{IFT}$ performance in rugby league players.

Notwithstanding the multiple physiological contributors to performance during the Yo-Yo IR1 and 30-15 IFT, high-intensity intermittent running, as determined by the Yo-Yo IR1, differentiates between playing standard, fatigue responses and match activity profiles in junior male rugby league players (20). Those classified as high fitness covered greater distance, high-speed running, number of collisions and number of repeated high-intensity efforts (20). Despite this, Gabbett and Seibold (9) reported no significant relationship between Yo-Yo IR1 distance and measures of match performance, including total ($r$ = 0.05), low-speed ($r$ = 0.04) and high-speed ($r$ = 0.09) distance as well as total collisions ($r$ = -0.70) and repeated high-intensity efforts ($r$ = -0.23) in male semi-professional players. As intermittent running during rugby match-play is frequently interspersed with collisions, which increases the physiological strain imposed (25), it is likely that this action alters the relationship between an entirely running-based intermittent field test and match-play as well as influencing the physiological determinants being evaluated (2). As such, limitations with the concurrent validity of the Yo-Yo IR1 and its association to rugby league match performance have been reported and suggest a rugby-specific measure of HIIR is warranted (2).

Gabbett and Seibold (9) suggest the need for a rugby-specific measure of HIIR that includes both repeated running efforts and collisions, and that could be included within current training practices (19). However, this could be difficult to standardise, assess large groups of players at once and could increase injury risk (6,27,28). An alternative approach that carries minimal injury risk is adopting certain components of physical contact but not the contact *per se*. For example, participants dropping to the ground in a prone position before returning to run imposed a greater physiological demand on participants during simulated match-play (27). Therefore, the inclusion this action during a test of HIIR might be worthwhile to increase the load imposed and more closely reflect that of match-play (6,27,29). However, before such a test can be used, it is essential to determine its validity against measures of rugby match performance.

The relationship between players' physical qualities and match-related movements has been studied during actual matches (9). However, in determining the concurrent validity of a test for measuring rugby-specific HIIR, it is necessary to consider contextual, positional and match-to-match variability in movement characteristics during rugby league match-play (21). Simulated match-play that controls for this variability might provide a useful tool for assessing the concurrent validity of a test. With this in mind, the purpose of this study was to establish the concurrent validity of a rugby-specific version of the Yo-Yo IR1 (prone Yo-Yo IR1) and Yo-Yo IR1 against the change in internal, external and perceptual loads between two bouts of simulated match-play.

## METHODS

### *Experimental Approach to the Problem*

The repeated measures design required all participants to perform the prone Yo-Yo IR1 and a sub-sample ($n$ = 16) to complete the Yo-Yo IR1 in a randomised order. One to two weeks after the prone Yo-Yo IR1, all participants completed the Rugby League Match Simulation Protocol for interchange players (RLMSP-i) (28). All trials were completed after a rest day, with participants having done no club- or leisure-based activity for at least 24 hours beforehand. Trials were performed on an outdoor synthetic grass pitch (3G all-weather surface) at the same time of day (± 2 hours). Mean temperature and humidity were 11.8 ± 3.4°C and 72.4 ± 1.9%, respectively. Participants were asked to maintain a similar diet for each testing day, refrain from caffeine 12 hours before, attend well-hydrated and wear the same clothing and footwear (studded boots) for each visit.

### *Subjects*

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

***Procedures***

*Standard and modified Yo-Yo Intermittent Recovery Test Level 1*

Participants undertook a standardised warm-up before completing as many 40 m shuttles as possible with a 10 s active recovery (walking) between shuttles as directed by an audio signal (23). Running speed for the test commenced at 10 km·h$^{-1}$ and increased 0.5 km·h$^{-1}$ approximately every 60 s until the participants could no longer maintain the required running speed. During the standard test, participants started in a two-point stance, whilst during the prone Yo-Yo IR1 participants were required to start each shuttle in a prone position with their head behind the start line, legs straight and chest in contact with the ground. Total distance was recorded after the second failed attempt to meet the start/finish line in the allocated time for both tests. Both the Yo-Yo IR1 (CV = 8.7%) (23) and modified Yo-Yo IR1 (CV = 9.9%) (6) are reported as reliable.

*Rugby League Movement Simulation for Interchange Players*

Participants were paired based on stature and body mass before repeating the standardised warm-up. The RLMSP-i consisted of two 23-minute bouts of activity interspersed with a 20-

minute passive recovery period to replicate the mean match demands of elite interchange rugby league players (28). Each bout consisted of 12 repeated cycles of activity and included two parts; ball in-play and ball out-of-play (for instructions see Ref. 28). Participants were instructed to perform each sprint 'maximally' to reproduce the demands of match-play. At contact, participants were instructed to flex the hips, knees and ankles while contacting a tackle shield held by their opponent (Gilbert Rugby, East Sussex, England) using their preferred shoulder. Three seconds after contact, the participants dropped into a prone position, returned to a standing position and waited for the next instruction.

*External response*

Movement characteristics were recorded using a 10 Hz microtechnology device (Optimete S5, Catapult Innovations, Melbourne, Australia) fitted into a custom-made vest positioned between the participant's scapulae. The mean ± SD number of satellites and HDOP was 13.8 ± 1.1 and 0.7 ± 0.1, respectively. Total distance was recorded and categorised into low (< 14.0 $km \cdot h^{-1}$) and high (> 14.1 $km \cdot h^{-1}$) intensities (25). Mean speed was calculated and peak speeds ($km \cdot h^{-1}$) of sprint A and B were measured; where sprint A and B represent the first and second 20.5 m sprint during each cycle of the simulation, respectively. Peak speed was determined as the peak absolute speed reached during the whole simulation. The fatigue index was calculated using all 48 sprint performances and the following equation: $Fatigue = 100 * EXP^{(slope/100)}-100$, where the slope is calculated using the line of best fit for: 100 x natural logarithm of sprint data) x (number of sprint -1) (12). The built-in 100 Hz triaxial accelerometer, gyroscope and magnetometer were used to determine high metabolic power (HMP) (> 20 $W \cdot kg^{-1}$). In-house analysis has revealed that the coefficient of variation for relative distance, low-speed running, high-speed running and peak speed were between 1.3-1.9%, 2.2-3.3%, 8.0-14.4% and 3.7-9.6%, respectively for bout 1 and 2 of the RLMSP-i (unpublished data).

*Internal and perceptual responses*

A heart rate (HR) monitor (Polar Electro Oy, Kempele, Finland) was wirelessly paired to the microtechnology device and analysed using custom software (Sprint, Version 5.1, Catapult Sports, VIC, Australia). Heart rate data were analysed as a percentage of the participant's peak HR recorded during the simulation (%$HR_{peak}$). Rating of perceived exertion (RPE) was recorded using the Borg 6-20 scale (3) during the simulation with a CV of 13.7 and 11.2% for bout 1 and 2, respectively. Blood lactate concentration ($[La]_b$ Arkray, Lactate Pro, Arkay, Kyoto, Japan; CV = 8.2%) was also measured from a fingertip capillary sample before the warm up and immediately after each bout.

## Statistical Analyses

Data are presented as mean ± SD. To evaluate any changes between RLMSP-i bouts, magnitude based-inferences were used with the following 90% confidence limits: < 0.5% most unlikely, 0.5-5% very unlikely, 5-25% unlikely, 25-75% possibly, 75-95% likely, 95-99.5 very likely, > 99.5 most likely. Magnitude of the observed change was assessed using the following thresholds: trivial < 0.2, small 0.2 - 0.6, moderate 0.6 - 1.2, large 1.2 - 2.0, and very large > 2.0 (17). To assess associations between a range of internal and external measures and distance covered during the prone Yo-Yo IR1, Pearson's correlation coefficient (*r*) with the following criteria were adopted to interpret the magnitude of the correlation between variables: < 0.1, *trivial*; >0.1-0.3, *small*; >0.3-0.5, *moderate*; >0.5-0.7, *large*; >0.7-0.9, *very large*; and >0.9-1.0, *almost perfect* (16), and was based on the change between bouts for relative total, low-speed and high-speed distance, mean speed and HMP, and raw values for fatigue index, the percentage change between sprints A and B, %$HR_{peak}$, RPE and $[La]_b$. If the confidence limits overlapped small positive and negative values when comparing the between-bout responses the effect was considered *unclear*. Statistical analysis was conducted using a predesigned spreadsheet for comparing means (14) and assessing correlations (15).

**RESULTS**

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

**Insert Table 1 Here**

There was a *large* negative correlation between total distance during both Yo-Yo IR1 tests and the percentage change in relative distance between bouts, but only *trivial* correlations for low- and high-speed distance. There was a *moderate* and *large* correlation between distance covered in the Yo-Yo IR1 and prone Yo-Yo IR1 with the percentage change in mean speed during the RLMSP-i. A *small* and *moderate* positive correlation was observed between distance covered in the Yo-Yo IR1 and prone Yo-Yo IR1 with percentage change in time spent at HMP, respectively. A *very large* positive correlation was observed between distance covered during the prone Yo-Yo IR1 and fatigue index and percentage difference between sprints A and B, with *large* correlations observed for the Yo-Yo IR1. All data are shown in Figure 1.

**Insert Figure 1 Here**

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

**Insert Figure 2 Here**

**Discussion**

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

The internal (86.2 ± 6.4 *cf.* 84.1 ± 8.2 $\%HR_{peak}$) and external (99 ± 5 *cf.* 95 ± 7 $m{\cdot}min^{-1}$) responses to the RLMSP-i were consistent with those observed for interchange players during match-play (29). The reduction in time at HMP between bouts, when expressed relative to time, was also comparable to rugby league match-play (22). Therefore, notwithstanding the challenges associated with replicating the true demands of a match (4), our data confirm that the RLMSP-i can be used to adequately replicate the internal and external response.

Our results indicated a *large* correlation between prone Yo-Yo IR1 and Yo-Yo IR1 distance and a player's change in relative distance during the RLMSP-i. Combined with the *large* and *moderate* relationship with change in mean speed between bouts of RLMSP-i, these results suggest that performance during both Yo-Yo IR1 tests can influence the running intensity that an individual sustains during simulated match-play as well as their ability to resist fatigue and recover between ball-in-play periods. As exercise time and total distance remained constant for all participants during the RLMSP-i, any changes in relative distance and mean speed between playing bouts are likely attributed to a progressive reduction in the sprint and sprint to contact speeds associated with peripheral (4) and central fatigue (24). Changes in sprint to contact speed might have resulted in some variability in displacement during the collision (i.e. greater fatigue resulted in participants not pushing the opponent back as far in the contact), thus potentially explaining the relationship between both Yo-Yo tests and relative distance.

Interestingly, only *trivial* relationships were observed between the Yo-Yo IR1 and prone Yo-Yo IR1 distance and the percentage change in low- or high-speed distance. We suspect the large between-participant variation resulted in a lack of systematic change between bouts. For example, for those players who achieved a prone Yo-Yo IR 1 distance of 800 m, the percentage change for low- and high-intensity running between bouts were between 0.1 to -4.4% and 0.4 to -10.3%, respectively. Moreover, the use of total, low- and high-speed distance might not necessarily be indicative of the load on players as the metabolic and mechanical costs of sport-specific movements are not represented (22).

We identified a *moderate* relationship between prone Yo-Yo IR1 distance and the change in time spent at HMP (> 20 $W \cdot kg^{-1}$) between bouts, suggesting those players who have greater rugby-specific HIIR can sustain combined accelerated and high-speed running during the RLMSP-i. In contrast, only a *small* relationship was observed between time spent at HMP and total distance during the Yo-Yo IR1, suggesting the inclusion of a metabolically demanding action during the prone Yo-Yo strengthens its relationship with simulated match-play. While HMP underestimates the metabolic costs associated with the collision (13), this metric does provide some evidence that rugby-specific HIIR is positively related to an individual's ability to perform and sustain metabolically demanding actions during a simulated match. That is to say, the prone Yo-Yo IR1 might provide further insight into a player's ability to maintain fundamental movements across playing bouts, including accelerating, decelerating, changing direction and getting up-and-down quickly.

A *large* correlation between Yo-Yo IR1 distance and fatigue index during the RLMSP-i was observed and this relationship was improved when using the prone Yo-Yo IR1 distance. These findings suggest that players who demonstrate greater HIIR and rugby-specific HIIR were better able to maintain sprint speed during the RLMSP-i. Whilst repeated sprint ability was not measured in this study, the *very large* correlation observed between prone Yo-Yo IR1 distance and the percentage difference between sprint A and B within each cycle of the RLMSP-i, agrees with previous research in soccer where a significant relationship ($r$ = -0.573) was observed between the distance covered during the Yo-Yo IR1 and mean speed during 7 x 35 m repeated sprints (18). Therefore, we propose that those who scored higher on the prone Yo-Yo IR1 were able use a greater proportion (~40%) of their aerobic capacity for the re-phosphorylation of adenosine triphosphate, reducing their reliance on anaerobic metabolism and associated fatigue (11). The relationship between the percentage difference for sprint A and B and distance was poorer for the Yo-Yo IR1 in comparison to the prone version. This suggests the increased emphasis on getting up and accelerating is more closely related to demands of repeated sprinting during the RLMSP-i.

A *moderate* and *large* negative correlation between Yo-Yo IR1 and prone Yo-Yo IR1 distance with $\%HR_{peak}$ during the RLMSP-i reaffirms the work of Krustrup et al. (23) who observed an inverse relationship between distance covered and $\%HR_{peak}$ during the Yo-Yo IR1. A *moderate* and *large* relationship was also observed between prone Yo-Yo IR1 distance and RPE during bouts 1 and 2, respectively. However, this relationship was weakened when total distance from the Yo-Yo IR1 was used. Collectively, these data indicate that HIIR is related to the internal and perceptual loads during the RLMSP-i, but that this relationship was stronger for the prone Yo-Yo IR1. As such, greater rugby-specific HIIR could allow players to perform the RLMSP-i with a lower internal load, possibly owing to a greater physiological capacity and improved recovery between ball-in-play periods. However, only *small* to *moderate* correlations were reported between prone Yo-Yo IR1 and Yo-Yo IR1 distance, and $[La]_{b,}$ which might be explained by poor reliability of this measure during the RLMSP-i (28), or the activity before sampling; as a time-frame of up to five minutes after completion was required for collection.

Despite similar movement demands, the reduction in external load between bouts (~5%) was smaller than that observed during match-play (~15%) (29), which is likely due to the difficulties in replicating the physical contact in the simulation (6,27). However, the use of simulated match-play strongly suggests that prone Yo-Yo IR1 distance is related to commonly used measures of load during activities that closely reflect match-play without interference from match-related factors. Further research might explore the validity of the prone Yo-Yo IR1 against performance measures during match-play using a multilevel mixed model approach that controls for other confounding variables and explores additional physical qualities. It is also important to note that the correlations observed in this study are based on academy and university-standard players who demonstrate a reduced prone Yo-Yo IR1 distance and lower body mass compared to elite Super League players (unpublished data). As such, future research might explore the relationship between prone Yo-Yo IR1 distance and measures of match performance in elite players. Finally, whilst we have provided evidence that rugby-specific HIIR is related to internal, external and perceptual measures of load, its influence on a player's ability to maintain skill performance is unknown.

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

## PRACTICAL APPLICATIONS

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

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Figure 1. Relationship between Prone Yo-Yo IRT (squares) and Yo-Yo IR1 (circles) distance with the changes in the external responses between bouts during the RLMSP-i. Correlation coefficient (*r*) are presented with 90% confidence intervals.

Figure 2. Relationship between Prone Yo-Yo IRT (squares) and Yo-Yo IR1 (circles) distance with the changes in the internal and perceptual responses during the RLMSP-i. Correlation coefficient (*r*) are presented with 90% confidence intervals.