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

Abstract

This study examined how starting each shuttle in the prone position altered the internal, external and perceptual responses to the Yo-Yo Intermittent Recovery Test Level 1. Using a randomized crossover design, 17 male rugby players completed the Yo-Yo IR1 and prone Yo-Yo IR1 on two separate occasions. External loads (via microtechnology), $\dot{V}O_2$, heart rate (HR), rating of perceived exertion (RPE) were measured at 160, 280 and 440 m (sub-maximal) and when the test was terminated (peak). The pre-to-post change in blood lactate concentration ($\Delta[La]_b$) was determined for both tests. All data were analysed using effect sizes and magnitude-based inferences. Between-trial differences (ES ± 90%CL) indicated total distance was *most likely* lower (-1.87 ± 0.19), whereas other measures of peak external load were *likely* to *very likely* higher during the prone Yo-Yo IR1 (0.62-1.80). Sub-maximal RPE was *likely* to *most likely* higher (0.40-0.96) and peak RPE *very likely* higher (0.63 ± 0.41) in the prone Yo-Yo IR1. The change in $[La]_b$ was *likely* higher after the prone Yo-Yo IRl. Mean HR was *possibly* lower at 440 m (-0.25 ± 0.29) as was peak HR (-0.26 ± 0.25) in the prone Yo-Yo IR1. $\dot{V}_E$, $\dot{V}O_2$ and $\dot{V}CO_2$ were *likely* to *very likely* higher at 280 and 440 m (ES = 0.36-1.22), while peak values were *possibly* to *likely* higher (ES = 0.23-0.37) in the prone Yo-Yo IR1. Adopting a prone position during the Yo-Yo IR1 increases the internal, perceptual and external responses, placing greater emphasis on metabolically demanding actions typical of rugby.

Key words: Fitness, physiology, performance, team sport, testing

Introduction

High-intensity efforts, involving repeated running and collisions, are important to success in rugby and are strongly associated with ‘critical’ moments (e.g. scoring/conceding a try) and match outcomes (Gabbett & Gahan, 2015; Kempton, Siroctic, Rampinini, & Coutts, 2015). For example, players perform up to 25 high-intensity efforts during rugby league match-play with ~56% of these preceding a try (Gabbett & Gahan, 2015). Players are engaged in metabolically demanding actions including collisions, followed by getting up from the floor, acceleration/deceleration and changes of direction (Atkins, 2006; Gabbett, 2005; Gabbett & Gahan, 2015; Kempton et al., 2015). These actions, when combined with running, impose a greater physiological load on an individual when compared to running alone (Mullen, Highton, & Twist, 2015; Oxendale, Highton, & Twist, 2017). As such, the ability to monitor an athlete using a test that employs match specific movements would be beneficial to understand performance capability (Gabbett, 2005) in collision sport athletes.

The Yo-Yo Intermittent Recovery Test (Yo-Yo IR1; Atkins, 2006) and 30-15 Intermittent Fitness Test (30-15$_{\mathrm{IFT}}$; Scott et al., 2015) have been used to assess the intermittent running ability of rugby players. However, as players must get up from the floor after a collision before moving to the next position ~40 times during match-play (i.e. joining the attack or retreating into the defensive line; Gissane, White, Kerr, & Jennings, 2001), incorporating some of these actions within traditional running-based tests might provide a better reflection of the metabolic and physiological responses typically observed during match-play. Whilst the inclusion of a collision during the test could increase the risk of injury, incorporating repeated up-and-downs might provide further insight into a player’s ability to perform this fundamental action, accelerate/decelerate and change direction alongside high-intensity running. The addition of these sport-specific actions has been used in simulations of rugby league match-play (Sykes, Nicholas, Lamb, & Twist, 2013), and our own in-house data has revealed strong associations (*r* = 0.48-0.78) between distance covered during a modified Yo-Yo IR1 (i.e. including an up and down) and measures of external (e.g. relative distance, high metabolic power [> 20 $W \cdot kg^{-1}$] and repeated sprinting) and internal (e.g. heart rate, RPE) responses during simulated match-play (Dobbin, Moss, Highton, Hunwicks, & Twist, 2017b). Despite the potential for this modified test, the physiological and performance responses to intermittent running tests with and without repeated up and down actions remain unknown. In particular, repeatedly getting up and down is likely to alter running performance when trying to maintain a given speed, while heavier players might be disadvantaged (Darrall-Jones et al., 2016). Furthermore, it seems prudent to investigate if, and to what extent, a modified test assesses distinct physical qualities, thus differentiating it from the original test and providing practitioners with further insight into an athlete's performance capabilities.

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

Methods

Participants

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

Design

Participants were required to attend the laboratory on two separate occasions at the same time of day (± 2 hours) separated by 2-5 days. During the initial visit, participants completed measures of stature and body mass before being randomly allocated to the Yo-Yo IR1 or prone Yo-Yo IR1. During the second visit, participants completed the remaining condition. Mean and standard deviation ambient temperature and humidity during the two trials was 16.5 ± 2.3°C and 59.0 ± 5.0%, respectively. During both trials, measurements of expired air, blood lactate concentration ($[La]_b$), rating of perceived exertion (RPE) and heart rate (HR) were recorded, and participants were required to wear a micro-technology device. Participants were asked to avoid exercise and replicate their diet in the 24 h before each visit as well as avoiding any form of supplementation (i.e. caffeine).

Procedures

Yo-Yo Intermittent Recovery Test Level 1

The Yo-Yo IR1 was performed as previously described (Krustrup et al., 2003) on an outdoor synthetic grass pitch (3G all-weather surface). Briefly, the Yo-Yo IR1 consisted of two 20-m shuttles followed by a 10 s active recovery (5 m deceleration, 180° change of direction and walk to the line), with all participants completing two practice shuttles at a low-speed before the test started. The test consisted of 4 shuttles at 10-13 km·h^{-1} (0-160 m), 3 shuttles at 13.5 km·h^{-1} (200-280 m) and 4 shuttles at 14.0 km·h^{-1} (320-440 m), thereafter the speed increased 0.5 km·h^{-1} every 8 shuttles (i.e. 760, 1080, 1400 m, etc.). Running speed was governed by an audio signal and participants were instructed to complete as many 40 m shuttles as possible. The test was terminated when the participant failed to reach the start line before the audio signal on a second occasion and the total distance covered recorded (no. shuttles x 40 m). During the prone Yo-Yo IR1, participants completed the same test described above but were required to start each shuttle from a prone position that was adopted at the end of each 10 s recovery phase with their head behind the start line, legs straight and chest in contact with the ground. All trials were completed individually to remove any external influences and the researcher provided consistent encouragement during the testing procedures. The coefficient of variation (9.9%) and intra-class correlation coefficient (0.98) has been determined for the prone Yo-Yo IR1 (Dobbin, Hunwicks, Highton & Twist, 2017a).

Internal and perceptual responses

Respiratory gas exchange was measured continuously using a portable, breath-by-breath system (Cosmed, K4b^2, Cosmed, Rome, Italy). Before each test, O_2 and CO_2 were calibrated with known concentrations. Upon completion, minute ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) data were averaged over 15-s epochs and matched with distance (based on time) to calculate mean sub-maximal values at 160 m, 280 m and 440 m. Finally, peak values for each variable were considered as the highest value achieved during the test. Previous literature has reported acceptable limits of agreement and mean bias for $\dot{V}_E$ (± 16.3 and ± 1.27 L·min^{-1}), $\dot{V}CO_2$ (± 0.67 and ± 0.06 L·min^{-1}), $\dot{V}O_2$ (± 0.82 and ± 0.08 L·min^{-1}), strong intra-class correlation (> 0.75) and low technical error of measurement (< 5%) between repeated trials exceeding 3-minutes when using the Cosmed K4 to measure $\dot{V}_E$, $\dot{V}O_2$, and $\dot{V}CO_2$ (Duffield, Dawson, Pinngton, & Wong, 2004). Heart rate, monitored via telemetry (Polar, FS1, Polar Electro, Oy Finland), was measured continuously during both trials to ascertain mean heart rate (HR_{mean}) at 160 m, 280 m and 440 m, and peak heart rate (HR_{peak}), defined as the highest recorded heart rate during the test.

Fingertip capillary blood samples (5 μL) were taken immediately before and within 30 s of completing the Yo-Yo IR1 tests and analysed for blood lactate concentration ($[La]_b$) (Lactate Pro analyser, Arkay, Kyoto, Japan). To remove any inter-analyser variability, the same Lactate Pro was used throughout (CV = 8.2%). After habituation to the scale and standardized instructions (Morris, Lamb, Cotterrell, & Buckley, 2009), rating of perceived exertion (RPE; in-house CV = 2.4%) was recorded after 160 m, 280 m, 440 m and at exercise cessation using the Borg 6-20 scale (Borg, 1998).

External responses

A 10 Hz micro-technology device fitted with a 100 Hz tri-axial accelerometer, gyroscope and magnetometer (Optimeye S5, Catapult Innovations, Melbourne, Australia) was worn in a custom-made vest with the unit positioned between the participant's scapulae. The available satellites and HDOP were 14.2 ± 1.2 (range 12.0–18.0) and 0.6 ± 0.1 (range 0.5–1.6), respectively. To exclude any possible intra-device variability, all participants wore the same GPS unit for each trial. Data were later downloaded and analysed (Sprint Version 5.1, Catapult Sports, VIC, Australia) for PlayerLoad^{TM} ($AU \cdot min^{-1}$), high metabolic power ($> 20\ W \cdot kg^{-1} \cdot min^{-1}$) and accelerations at 0-2, 2-3, 3-4 and 4-20 $m \cdot s^{-1}$ ($m \cdot min^{-1}$). This micro-technology device is reliable and valid for measuring the movement of team sport athletes (Johnston, Watsford, Kelly, Pine, & Spurrs, 2014).

Statistical analysis

All data are presented as mean ± SD and represent all participants (except for sub-maximal responses at 440 m; $n = 15$). Magnitude-based inferences (MBI) and effect sizes with 90% confidence limits were used, with effect sizes calculated as the difference between trials divided by the pooled SD. This approach was applied to the peak movement, physiological and perceptual responses as well as sub-maximal responses at three sub-maximal distances of each test (160 m, 280 m and 440 m). Threshold values for effect sizes were: 0.0-0.2, *trivial*; 0.2-0.6, *small*; 0.6-1.2, *moderate*; 1.2-2.0, *large*; >2.0, *very large* (Hopkins, Marshall, Batterham, Hanin, 2009). Threshold probabilities for a mechanistic effect based on the 90% confidence limits were: 25-75% *possibly*, 75-95% *likely*, 95-99% *very likely* and > 99.5 *most likely* (Batterham & Hopkins, 2006). If the likely range of a true value overlapped substantially positive or negative values, the change was classified as *unclear*. To ascertain the relationship between the two tests, and with body mass, Pearson's correlation (r) was used to determine the correlation coefficient with the following criteria applied: < 0.1, *trivial*; >0.1-0.3, *small*; >0.3-0.5, *moderate*; >0.5-0.7, *large*; >0.7-0.9, *very large*; and >0.9-1.0, *almost perfect*. In addition, linear regression was used to determine how much of the prone Yo-Yo IR1 distance was explained by the Yo-Yo IR1 distance. Statistical analysis was conducted using a predesigned spreadsheet for comparing means (Hopkins, 2006), and correlation and regression (Hopkins, 2015).

Results

Total distance was *most likely* lower during the prone Yo-Yo IR1 with a mean difference of -346 ± 115 m. PlayerLoad™ and high metabolic power were *very likely* and *most likely* higher during the prone Yo-Yo IR1 compared to the Yo-Yo IR1, respectively (Figure 1 and 2). The peak acceleration responses across all thresholds were *likely* to *very likely* higher during the prone Yo-Yo IR1 compared to the Yo-Yo IR1 (Table 1). These higher loads are reflected in the *possibly* to *very likely* higher $\Delta[La]_b$, peak RPE and peak metabolic responses during the prone Yo-Yo IR1 compared the Yo-Yo IR1 (Table 1, Figure 1).

*** Insert Table 1 About Here***

Insert Figure 1 About Here

Insert Figure 2 About Here

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

Insert Table 2 About Here

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

Discussion

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

Total distance was lower during the prone Yo-Yo IR1 compared to standard Yo-Yo IR1 trial. It is likely that the repeated up-and-down action emphasised players having to accelerate to maintain a given speed, which was responsible for a greater energetic demand during the prone Yo-Yo IR1 compared with the Yo-Yo IR1, which in turn, caused earlier exercise cessation. As the audio signal did not account for the time taken to get up from the prone position, participants were required to place greater emphasis on the initial acceleration during this trial to cover the 40 m within the allocated time. Greater distances covered within all acceleration thresholds, higher metabolic power and PlayerLoad™ during the prone Yo-Yo IR1 further support this notion (see Figure 2). Getting up from the floor and accelerating would also increase upper- and lower-body muscle activation at the start of the shuttle. Compared to the standard Yo-Yo IR1, these additional actions would likely result in a greater reliance on fast twitch muscle fibres and subsequent metabolite disturbances that are associated with fatigue, including K+ efflux, which has been reported to impact the transmission of surface member action potential (Westerblad, Allen, & Lannergren, 2002; Allen, Lamb, & Westerbald, 2008). Furthermore, an increase in Pi, ADP and a decrease in ATP are reported to impact the sarcoplasmic reticulum calcium ion (Ca^{2+}) uptake, and the increase in Pi and H+ ions can lower the pH which negatively impacts on Ca^{2+} activated muscular force (Allen et al., 2008; Hvid, Gejl, Bech, Nygaard, Jensen, Fransend & Ørtenbald, 2013). It is also important to acknowledge the role of the central nervous system and that an increase in perception of effort and feedback from the muscle afferents might have reduced the neural drive (i.e. greater corollary discharge) (Smiraul, Dantas, Nakamura & Pereira, 2013); thus, potentially explaining the lower distance covered in the prone Yo-Yo IR1.

Our results indicate that no practically meaningful difference was observed in sub-maximal or peak heart rate. These findings agree with Haydar, Haddad, Ahmaidi, and Buchheit (2011) who reported no differences in HR_{peak} when participants completed several modified (continuous, linear and greater number of changes of direction) $30\text{-}15_{IFT}$ tests. However, the results appear to contrast those of Ashton and Twist (2015), who observed a *possibly* lower HR_{mean} during an intermittent shuttle test with an increased number of directional changes. Whilst it is important to acknowledge that neither study adopted the prone position during their investigations, they provide some, albeit conflicting, evidence regarding changes in HR when the mechanical load is altered during intermittent running. It is noteworthy that HR_{mean} at 400 m and HR_{peak} were *possibly* lower during the latter stages of the prone Yo-Yo IR1 compared to the Yo-Yo IR1, despite the increased acceleratory demands. One possible explanation is the contrasting body positions during the two trials, which might have had a small influence on heart rate (Buchheit, Haddad, Laursen, & Ahmaidi, 2009). Furthermore, as the prone Yo-Yo IR1 resulted in greater accelerated running during the outward shuttle due to the time lost when getting up, this speed was continued into the inward shuttle unnecessarily (Figure 2). Such an approach likely resulted in participants slowing down towards the end of the inward shuttle, perhaps explaining a slightly lower HR. Nonetheless, it is important to note that the difference between the tests (2-3 $b \cdot min^{-1}$) was of little practical significance when considering the reliability of this measure during the Yo-Yo IR1 (Deprez et al., 2014).

$\dot{V}O_{2peak}$ was *likely* higher during the prone Yo-Yo IR1 at exercise cessation, and was *unclear*, *likely* and *very likely* higher, respectively, during each of the sub-maximal distances when compared to the Yo-Yo IR1. These findings agree with Buchheit, Bishop, Haydar, Nakamura, and Ahmaidi (2010) who reported *possibly* higher $\dot{V}O_2$ responses when incorporating 180° change of direction during repeated shuttle running. Whilst this protocol is different to that used in the current study, these findings suggest that changes in the mechanical loading through a change of direction or adopting a prone position during shuttle-based and incremental shuttle running can alter the $\dot{V}O_2$ response. These findings are, however, in contrast to those of Hader et al. (2014) who reported no differences in O_2 demand during repeated sprinting with and without changes of direction. As the authors note, the increase in O_2 demand associated with changes of direction was probably offset by the reduction in running speed. In contrast, the present study controlled the running speed during both tests, though potential differences in activity (i.e. getting into the prone position) during the rest period should be acknowledged.

Unsurprisingly, $\dot{V}CO_2$ increased as both tests progressed and was higher during the prone Yo-Yo IR1. The higher $\dot{V}CO_2$ reflects an increased metabolism to maintain a higher ATP turnover that was required during the prone Yo-Yo IR1 trial due the greater accelerated running. It is possible that the emphasis on accelerated running was lower at 160 m where the time permitted to cover the 40 m was longer; thus, explaining the unclear difference in $\dot{V}CO_2$ compared to 280 and 440 m. Furthermore, $\dot{V}_E$ was *possibly* higher at exercise cessation and was *most likely* higher at 280 m and 440 m during the prone Yo-Yo IR1. These results support the notion that during the prone Yo-Yo IR1 there was a greater and earlier reliance anaerobic metabolism which might explain the higher $[La]_b$ and $\dot{V}CO_2$ production. The physiological responses to starting the Yo-Yo IR1 from a prone position are consistent with studies reporting an increased reliance on anaerobic metabolism with accelerated running (Zamparo et al., 2016; Jameson & Ring, 2000).

Between-trial differences in RPE revealed a higher perception of effort at each sub-maximal distance and at exercise cessation of the prone Yo-Yo IR1. Such findings might be explained by both peripheral and central factors. Greater and earlier production of metabolic by-products during the prone Yo-Yo IR1 could have activated group III and IV afferents (Enoke & Duchateau, 2008) and compromised performance in an attempt to limit disturbances through inhibition of the central motor drive (Amann et al., 2013). In contrast, higher RPE during the prone Yo-Yo IR1 might be explained by corollary discharge from premotor and motor areas of the cortex responsible for muscle contraction (de Morree, Klein & Marcora, 2014). If so, our results might suggest that the increase in RPE is a reflection of the greater corollary discharge in order to in maintain the required running speed during the prone Yo-Yo IR1 through greater accelerated running (Smiraul, Dantas, Nakamura & Pereira, 2013). Whilst is it beyond the scope of this study to determine the exact mechanism, our results support the notion that the addition of starting the Yo-Yo IR1 in the prone position increases an individual's rating of perceived exertion.

Both versions of the Yo-Yo IR1 could be considered maximal, as evidenced by attainment of (similar) HR_{peak} (< ±10 $b \cdot min^{-1}$ age-predicted HR_{peak}), $[La]_b$ (≥ 8 $mmol \cdot L^{-1}$), near-maximal RPEs and similar $\dot{V}O_{2peak}$ values to those previously reported for rugby union (Duthie, Pyne, & Hooper, 2003) and league players (Gabbett, 2005). The large covariance (76%) between tests suggests that both tests can be used to assess intermittent running ability. However, it is worth noting that 24% of player performance on the prone Yo-Yo IR1 is not explained by intermittent running (as determined using the Yo-Yo IR1) and likely refers to their ability to get from the prone position and accelerate during the early stages of the outward shuttle. As such, the prone Yo-Yo IR1 allows practitioners to assess distinct qualities that are specific to collision sports beyond that of the Yo-Yo IR1, including their ability to sustain time above 20 W·kg^{-1} ($r = 0.48$), mean speed ($r = 0.64$), sprint speed (r - 0.71) and repeated sprints ($r = 0.78$) over two bouts of simulated match-play (Dobbin et al., 2017b). Given the importance of such actions during collision sports it is essential that practitioners can evaluate a player's capability to repeatedly perform these actions as well as evaluating and focusing training practices.

The trivial and small correlations between body mass, distance covered and the change in distance covered between tests suggest a higher body mass does not necessarily impair performance during the prone Yo-Yo IR1. These observations also contradict those of Darrall-Jones and colleagues (2016) who reported body mass to influence peak running speed, and thus performance, attained in the 30-15$_{\text{IFT}}$. That the players studied by Darrall-Jones et al. (2016) were considerably heavier (~15-20 kg) with greater heterogeneity of body mass, might explain these differences. Future studies might explore the relationship between body mass and distance covered during the prone Yo-Yo further, using a large sample across all playing positions in rugby league.

Conclusions

This study has confirmed that the addition of a rugby-specific action decreases the total distance covered during the Yo-Yo IR1. We postulate that this change in Yo-Yo IR1 performance is attributed to increases the metabolic, cardiovascular and perceptual responses caused by starting each shuttle from a prone position. This is likely a consequence of greater involvement of the upper-body musculature to get up from the floor quickly and the greater emphasis placed on accelerated running to meet the required running speed. The large covariance between tests suggests that performance on one can, to some degree, explain performance on the other. However, with a proportion of performance not explained by a running-based Yo-Yo IR1, it likely refers to the ability to perform distinct metabolically demanding actions typical of collision sports. The results of this study have several practical applications. Firstly, the increased metabolic, physiological and perceptual responses elicited by adopting the prone position prior to accelerated running suggest this as a method that can be used by coaches to modify training load within the periodized plan. This option might be preferable for coaches in the lead up to match-play, enabling exposure to a high training load without the added injury risk that might accompany collisions/tackles (Gabbett, Jenkins & Abernethy, 2011). In addition, the test allows coaches to evaluate several determinants of rugby specific performance for monitoring purposes over the season and to assess the efficacy of specific training interventions. Future studies might wish to investigate the concurrent validity of the prone Yo-Yo IR1 and its relationship to match performance. Furthermore, the sensitivity of the prone Yo-Yo IR1 to detect a meaningful change in performance after a period of training would be practically useful.

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Figure 1. Percentage difference in metabolic, physiological and external responses measured for Yo-Yo IR1 and prone Yo-Yo IR1 (bars indicated uncertainty in the true mean difference with 90% confidence intervals). Trivial areas were calculated from the smallest worthwhile change.

Figure 2. Changes in PlayerLoad™ (upper panel) and metabolic power (lower panel) for one representative participant during two consecutive shuttles at 14 km·h^{-1} during the Yo-Yo IR1 and prone Yo-Yo IR1.

Table 1. Peak external and internal responses to the Yo-Yo IR1 and prone Yo-Yo IR1

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

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

Table 2. Sub-maximal cardiovascular, perceptual and metabolic responses to the Yo-Yo IR1 and prone Yo-Yo IR1.

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

Note: Mean heart rate (HR_{mean}), rating of perceived exertion (RPE), minute ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_{2peak}$) and carbon dioxide production ($\dot{V}CO_2$). ↑ = increase. ↓ decrease.