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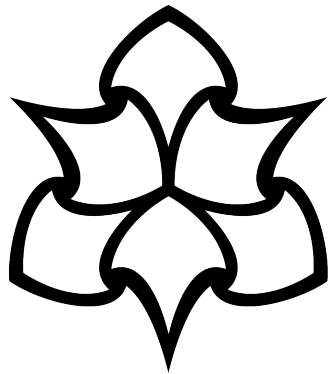
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Dobbin, Nicholas and Moss, Samantha and Highton, Jamie and Twist, Craig (2018) *An examination of a modified Yo-Yo test to measure intermittent running performance in rugby players*. *European Journal of Sport Science*, 18 (8). pp. 1068-1076. ISSN 1746-1391

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

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1 Abstract

2 This study examined how starting each shuttle in the prone position altered the internal,
3 external and perceptual responses to the Yo-Yo Intermittent Recovery Test Level 1. Using a
4 randomized crossover design, 17 male rugby players completed the Yo-Yo IR1 and prone Yo-
5 Yo IR1 on two separate occasions. External loads (via microtechnology), $\dot{V}O_2$, heart rate (HR),
6 rating of perceived exertion (RPE) were measured at 160, 280 and 440 m (sub-maximal) and
7 when the test was terminated (peak). The pre-to-post change in blood lactate concentration
8 ($\Delta[La]_b$) was determined for both tests. All data were analysed using effect sizes and
9 magnitude-based inferences. Between-trial differences ($ES \pm 90\%CL$) indicated total distance
10 was *most likely* lower (-1.87 ± 0.19), whereas other measures of peak external load were *likely*
11 to *very likely* higher during the prone Yo-Yo IR1 (0.62-1.80). Sub-maximal RPE was *likely* to
12 *most likely* higher (0.40-0.96) and peak RPE *very likely* higher (0.63 ± 0.41) in the prone Yo-
13 Yo IR1. The change in $[La]_b$ was *likely* higher after the prone Yo-Yo IR1. Mean HR was
14 *possibly* lower at 440 m (-0.25 ± 0.29) as was peak HR (-0.26 ± 0.25) in the prone Yo-Yo IR1.
15 \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
16 peak values were *possibly* to *likely* higher ($ES = 0.23-0.37$) in the prone Yo-Yo IR1. Adopting
17 a prone position during the Yo-Yo IR1 increases the internal, perceptual and external
18 responses, placing greater emphasis on metabolically demanding actions typical of rugby.

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

1 **Introduction**

2 High-intensity efforts, involving repeated running and collisions, are important to
3 success in rugby and are strongly associated with ‘critical’ moments (e.g. scoring/conceding a
4 try) and match outcomes (Gabbett & Gahan, 2015; Kempton, Siroctic, Rampinini, & Coutts,
5 2015). For example, players perform up to 25 high-intensity efforts during rugby league
6 match-play with ~56% of these preceding a try (Gabbett & Gahan, 2015). Players are engaged
7 in metabolically demanding actions including collisions, followed by getting up from the floor,
8 acceleration/deceleration and changes of direction (Atkins, 2006; Gabbett, 2005; Gabbett &
9 Gahan, 2015; Kempton et al., 2015). These actions, when combined with running, impose a
10 greater physiological load on an individual when compared to running alone (Mullen, Highton,
11 & Twist, 2015; Oxendale, Highton, & Twist, 2017). As such, the ability to monitor an athlete
12 using a test that employs match specific movements would be beneficial to understand
13 performance capability (Gabbett, 2005) in collision sport athletes.

14 The Yo-Yo Intermittent Recovery Test (Yo-Yo IR1; Atkins, 2006) and 30-15
15 Intermittent Fitness Test (30-15_{IFT}; Scott et al., 2015) have been used to assess the intermittent
16 running ability of rugby players. However, as players must get up from the floor after a collision
17 before moving to the next position ~40 times during match-play (i.e. joining the attack or
18 retreating into the defensive line; Gissane, White, Kerr, & Jennings, 2001), incorporating some
19 of these actions within traditional running-based tests might provide a better reflection of the
20 metabolic and physiological responses typically observed during match-play. Whilst the
21 inclusion of a collision during the test could increase the risk of injury, incorporating repeated
22 up-and-downs might provide further insight into a player’s ability to perform this fundamental
23 action, accelerate/decelerate and change direction alongside high-intensity running. The
24 addition of these sport-specific actions has been used in simulations of rugby league match-
25 play (Sykes, Nicholas, Lamb, & Twist, 2013), and our own in-house data has revealed strong

1 associations ($r = 0.48-0.78$) between distance covered during a modified Yo-Yo IR1 (i.e.
2 including an up and down) and measures of external (e.g. relative distance, high metabolic
3 power [$> 20 \text{ W}\cdot\text{kg}^{-1}$] and repeated sprinting) and internal (e.g. heart rate, RPE) responses during
4 simulated match-play (Dobbin, Moss, Highton, Hunwicks, & Twist, 2017b). Despite the
5 potential for this modified test, the physiological and performance responses to intermittent
6 running tests with and without repeated up and down actions remain unknown. In particular,
7 repeatedly getting up and down is likely to alter running performance when trying to maintain
8 a given speed, while heavier players might be disadvantaged (Darrall-Jones et al., 2016).
9 Furthermore, it seems prudent to investigate if, and to what extent, a modified test assesses
10 distinct physical qualities, thus differentiating it from the original test and providing
11 practitioners with further insight into an athlete's performance capabilities.

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

24

25 **Methods**

1 ***Participants***

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

7 ***Design***

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

18 ***Procedures***

19 *Yo-Yo Intermittent Recovery Test Level 1*

20 The Yo-Yo IR1 was performed as previously described (Krustrup et al., 2003) on an
21 outdoor synthetic grass pitch (3G all-weather surface). Briefly, the Yo-Yo IR1 consisted of two
22 20-m shuttles followed by a 10 s active recovery (5 m deceleration, 180° change of direction
23 and walk to the line), with all participants completing two practice shuttles at a low-speed

1 before the test started. The test consisted of 4 shuttles at 10-13 km·h⁻¹ (0-160 m), 3 shuttles at
2 13.5 km·h⁻¹ (200-280 m) and 4 shuttles at 14.0 km·h⁻¹ (320-440 m), thereafter the speed
3 increased 0.5 km·h⁻¹ every 8 shuttles (i.e. 760, 1080, 1400 m, etc.). Running speed was
4 governed by an audio signal and participants were instructed to complete as many 40 m shuttles
5 as possible. The test was terminated when the participant failed to reach the start line before
6 the audio signal on a second occasion and the total distance covered recorded (no. shuttles x
7 40 m). During the prone Yo-Yo IR1, participants completed the same test described above but
8 were required to start each shuttle from a prone position that was adopted at the end of each 10
9 s recovery phase with their head behind the start line, legs straight and chest in contact with the
10 ground. All trials were completed individually to remove any external influences and the
11 researcher provided consistent encouragement during the testing procedures. The coefficient
12 of variation (9.9%) and intra-class correlation coefficient (0.98) has been determined for the
13 prone Yo-Yo IR1 (Dobbin, Hunwicks, Highton & Twist, 2017a).

14 *Internal and perceptual responses*

15 Respiratory gas exchange was measured continuously using a portable, breath-by-
16 breath system (Cosmed, K4b², Cosmed, Rome, Italy). Before each test, O₂ and CO₂ were
17 calibrated with known concentrations. Upon completion, minute ventilation (\dot{V}_E), oxygen
18 uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) data were averaged over 15-s epochs and
19 matched with distance (based on time) to calculate mean sub-maximal values at 160 m, 280 m
20 and 440 m. Finally, peak values for each variable were considered as the highest value achieved
21 during the test. Previous literature has reported acceptable limits of agreement and mean bias
22 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
23 L·min⁻¹), strong intra-class correlation (> 0.75) and low technical error of measurement ($< 5\%$)
24 between repeated trials exceeding 3-minutes when using the Cosmed K4 to measure \dot{V}_E , $\dot{V}O_2$,

1 and $\dot{V}CO_2$ (Duffield, Dawson, Pinngton, & Wong, 2004). Heart rate, monitored via telemetry
2 (Polar, FS1, Polar Electro, Oy Finland), was measured continuously during both trials to
3 ascertain mean heart rate (HR_{mean}) at 160 m, 280 m and 440 m, and peak heart rate (HR_{peak}),
4 defined as the highest recorded heart rate during the test.

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

12 *External responses*

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

23 *Statistical analysis*

1 All data are presented as mean \pm SD and represent all participants (except for sub-
2 maximal responses at 440 m; $n = 15$). Magnitude-based inferences (MBI) and effect sizes with
3 90% confidence limits were used, with effect sizes calculated as the difference between trials
4 divided by the pooled SD. This approach was applied to the peak movement, physiological and
5 perceptual responses as well as sub-maximal responses at three sub-maximal distances of each
6 test (160 m, 280 m and 440 m). Threshold values for effect sizes were: 0.0-0.2, *trivial*; 0.2-0.6,
7 *small*; 0.6-1.2, *moderate*; 1.2-2.0, *large*; >2.0 , *very large* (Hopkins, Marshall, Batterham,
8 Hanin, 2009). Threshold probabilities for a mechanistic effect based on the 90% confidence
9 limits were: 25-75% *possibly*, 75-95% *likely*, 95-99% *very likely* and > 99.5 *most likely*
10 (Batterham & Hopkins, 2006). If the likely range of a true value overlapped substantially
11 positive or negative values, the change was classified as *unclear*. To ascertain the relationship
12 between the two tests, and with body mass, Pearson's correlation (r) was used to determine the
13 correlation coefficient with the following criteria applied: < 0.1 , *trivial*; $>0.1-0.3$, *small*; $>0.3-$
14 0.5 , *moderate*; $>0.5-0.7$, *large*; $>0.7-0.9$, *very large*; and $>0.9-1.0$, *almost perfect*. In addition,
15 linear regression was used to determine how much of the prone Yo-Yo IR1 distance was
16 explained by the Yo-Yo IR1 distance. Statistical analysis was conducted using a predesigned
17 spreadsheet for comparing means (Hopkins, 2006), and correlation and regression (Hopkins,
18 2015).

19

20 **Results**

21 Total distance was *most likely* lower during the prone Yo-Yo IR1 with a mean difference of -
22 346 ± 115 m. PlayerLoad™ and high metabolic power were *very likely* and *most likely* higher
23 during the prone Yo-Yo IR1 compared to the Yo-Yo IR1, respectively (Figure 1 and 2). The
24 peak acceleration responses across all thresholds were *likely* to *very likely* higher during the
25 prone Yo-Yo IR1 compared to the Yo-Yo IR1 (Table 1). These higher loads are reflected in

1 the *possibly* to *very likely* higher $\Delta[\text{La}]_b$, peak RPE and peak metabolic responses during the
2 prone Yo-Yo IR1 compared the Yo-Yo IR1 (Table 1, Figure 1).

3 *** Insert Table 1 About Here***

4 ***Insert Figure 1 About Here***

5 ***Insert Figure 2 About Here***

6 Differences between sub-maximal metabolic and HR responses at 160 m were *unclear*,
7 although there was a *likely* higher RPE during the prone Yo-Yo trial (Table 2). The effect on
8 HR was *unclear* at 160 m and 280 m, but RPE, \dot{V}_E , $\dot{V}\text{CO}_2$ and $\dot{V}\text{O}_2$ were *likely* to *very likely*
9 higher during the prone Yo-Yo IR1 (Table 2). At 440 m HR was *possibly* lower, while RPE
10 and metabolic responses were *very* to *most likely* higher during the prone Yo-Yo IR1 compared
11 to the Yo-Yo IR1 (Table 2).

12 ***Insert Table 2 About Here***

13 There was a *large* correlation for distance covered between the Yo-Yo IR1 and prone Yo-Yo
14 IR1 ($r = 0.87$) and linear regression revealed that performance on the Yo-Yo IR1 explained
15 76% ($R^2 = 0.76$) of the variance during the prone Yo-Yo IR1. A *small* and *trivial* correlation
16 was observed between body mass and the distance covered during prone Yo-Yo IR1 ($r = -0.28$,
17 90% CL $-0.62 - 0.15$) and Yo-Yo IR1 ($r = -0.07$, 90% CL $-0.47 - 0.36$), respectively. A *small*
18 correlation was also observed between body mass and the difference in distance covered
19 between tests ($r = 0.27$, 90% CL $-0.16 - 0.61$). Body mass explained 8% ($R^2 = 0.08$) of prone
20 Yo-Yo IR1 performance, 0.4% ($R^2 = 0.004$) of Yo-Yo IR1 performance and 7.2% ($R^2 = 0.072$)
21 of the differences between tests.

22

1 Discussion

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

10 Total distance was lower during the prone Yo-Yo IR1 compared to standard Yo-Yo
11 IR1 trial. It is likely that the repeated up-and-down action emphasised players having to
12 accelerate to maintain a given speed, which was responsible for a greater energetic demand
13 during the prone Yo-Yo IR1 compared with the Yo-Yo IR1, which in turn, caused earlier
14 exercise cessation. As the audio signal did not account for the time taken to get up from the
15 prone position, participants were required to place greater emphasis on the initial acceleration
16 during this trial to cover the 40 m within the allocated time. Greater distances covered within
17 all acceleration thresholds, higher metabolic power and PlayerLoad™ during the prone Yo-Yo
18 IR1 further support this notion (see Figure 2). Getting up from the floor and accelerating would
19 also increase upper- and lower-body muscle activation at the start of the shuttle. Compared to
20 the standard Yo-Yo IR1, these additional actions would likely result in a greater reliance on
21 fast twitch muscle fibres and subsequent metabolite disturbances that are associated with
22 fatigue, including K^+ efflux, which has been reported to impact the transmission of surface
23 member action potential (Westerblad, Allen, & Lannergren, 2002; Allen, Lamb, & Westerbald,
24 2008). Furthermore, an increase in P_i , ADP and a decrease in ATP are reported to impact the
25 sarcoplasmic reticulum calcium ion (Ca^{2+}) uptake, and the increase in P_i and H^+ ions can lower

1 the pH which negatively impacts on Ca^{2+} activated muscular force (Allen et al., 2008; Hvid,
2 Gejl, Bech, Nygaard, Jensen, Fransend & Ørtenbald, 2013). It is also important to acknowledge
3 the role of the central nervous system and that an increase in perception of effort and feedback
4 from the muscle afferents might have reduced the neural drive (i.e. greater corollary discharge)
5 (Smiraul, Dantas, Nakamura & Pereira, 2013); thus, potentially explaining the lower distance
6 covered in the prone Yo-Yo IR1.

7 Our results indicate that no practically meaningful difference was observed in sub-
8 maximal or peak heart rate. These findings agree with Haydar, Haddad, Ahmaidi, and Buchheit
9 (2011) who reported no differences in HR_{peak} when participants completed several modified
10 (continuous, linear and greater number of changes of direction) 30-15_{IFT} tests. However, the
11 results appear to contrast those of Ashton and Twist (2015), who observed a *possibly* lower
12 HR_{mean} during an intermittent shuttle test with an increased number of directional changes.
13 Whilst it is important to acknowledge that neither study adopted the prone position during their
14 investigations, they provide some, albeit conflicting, evidence regarding changes in HR when
15 the mechanical load is altered during intermittent running. It is noteworthy that HR_{mean} at 400
16 m and HR_{peak} were *possibly* lower during the latter stages of the prone Yo-Yo IR1 compared
17 to the Yo-Yo IR1, despite the increased acceleratory demands. One possible explanation is the
18 contrasting body positions during the two trials, which might have had a small influence on
19 heart rate (Buchheit, Haddad, Laursen, & Ahmaidi, 2009). Furthermore, as the prone Yo-Yo
20 IR1 resulted in greater accelerated running during the outward shuttle due to the time lost when
21 getting up, this speed was continued into the inward shuttle unnecessarily (Figure 2). Such an
22 approach likely resulted in participants slowing down towards the end of the inward shuttle,
23 perhaps explaining a slightly lower HR. Nonetheless, it is important to note that the difference
24 between the tests ($2\text{-}3 \text{ b}\cdot\text{min}^{-1}$) was of little practical significance when considering the
25 reliability of this measure during the Yo-Yo IR1 (Deprez et al., 2014).

1 $\dot{V}O_{2peak}$ was *likely* higher during the prone Yo-Yo IR1 at exercise cessation, and was
2 *unclear*, *likely* and *very likely* higher, respectively, during each of the sub-maximal distances
3 when compared to the Yo-Yo IR1. These findings agree with Buchheit, Bishop, Haydar,
4 Nakamura, and Ahmaidi (2010) who reported *possibly* higher $\dot{V}O_2$ responses when
5 incorporating 180° change of direction during repeated shuttle running. Whilst this protocol is
6 different to that used in the current study, these findings suggest that changes in the mechanical
7 loading through a change of direction or adopting a prone position during shuttle-based and
8 incremental shuttle running can alter the $\dot{V}O_2$ response. These findings are, however, in
9 contrast to those of Hader et al. (2014) who reported no differences in O_2 demand during
10 repeated sprinting with and without changes of direction. As the authors note, the increase in
11 O_2 demand associated with changes of direction was probably offset by the reduction in
12 running speed. In contrast, the present study controlled the running speed during both tests,
13 though potential differences in activity (i.e. getting into the prone position) during the rest
14 period should be acknowledged.

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

1 an increased reliance on anaerobic metabolism with accelerated running (Zamparo et al., 2016;
2 Jameson & Ring, 2000).

3 Between-trial differences in RPE revealed a higher perception of effort at each sub-
4 maximal distance and at exercise cessation of the prone Yo-Yo IR1. Such findings might be
5 explained by both peripheral and central factors. Greater and earlier production of metabolic
6 by-products during the prone Yo-Yo IR1 could have activated group III and IV afferents
7 (Enoke & Duchateau, 2008) and compromised performance in an attempt to limit disturbances
8 through inhibition of the central motor drive (Amann et al., 2013). In contrast, higher RPE
9 during the prone Yo-Yo IR1 might be explained by corollary discharge from premotor and
10 motor areas of the cortex responsible for muscle contraction (de Morree, Klein & Marcora,
11 2014). If so, our results might suggest that the increase in RPE is a reflection of the greater
12 corollary discharge in order to in maintain the required running speed during the prone Yo-Yo
13 IR1 through greater accelerated running (Smiraul, Dantas, Nakamura & Pereira, 2013). Whilst
14 is it beyond the scope of this study to determine the exact mechanism, our results support the
15 notion that the addition of starting the Yo-Yo IR1 in the prone position increases an individual's
16 rating of perceived exertion.

17 Both versions of the Yo-Yo IR1 could be considered maximal, as evidenced by
18 attainment of (similar) HR_{peak} ($< \pm 10 \text{ b} \cdot \text{min}^{-1}$ age-predicted HR_{peak}), $[La]_b$ ($\geq 8 \text{ mmol} \cdot \text{L}^{-1}$), near-
19 maximal RPEs and similar $\dot{V}O_{2peak}$ values to those previously reported for rugby union (Duthie,
20 Pyne, & Hooper, 2003) and league players (Gabbett, 2005). The large covariance (76%)
21 between tests suggests that both tests can be used to assess intermittent running ability.
22 However, it is worth noting that 24% of player performance on the prone Yo-Yo IR1 is not
23 explained by intermittent running (as determined using the Yo-Yo IR1) and likely refers to
24 their ability to get from the prone position and accelerate during the early stages of the outward
25 shuttle. As such, the prone Yo-Yo IR1 allows practitioners to assess distinct qualities that are

1 specific to collision sports beyond that of the Yo-Yo IR1, including their ability to sustain time
2 above $20 \text{ W} \cdot \text{kg}^{-1}$ ($r = 0.48$), mean speed ($r = 0.64$), sprint speed ($r = 0.71$) and repeated sprints
3 ($r = 0.78$) over two bouts of simulated match-play (Dobbin et al., 2017b). Given the importance
4 of such actions during collision sports it is essential that practitioners can evaluate a player's
5 capability to repeatedly perform these actions as well as evaluating and focusing training
6 practices.

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

16

17 **Conclusions**

18 This study has confirmed that the addition of a rugby-specific action decreases the total
19 distance covered during the Yo-Yo IR1. We postulate that this change in Yo-Yo IR1
20 performance is attributed to increases the metabolic, cardiovascular and perceptual responses
21 caused by starting each shuttle from a prone position. This is likely a consequence of greater
22 involvement of the upper-body musculature to get up from the floor quickly and the greater
23 emphasis placed on accelerated running to meet the required running speed. The large
24 covariance between tests suggests that performance on one can, to some degree, explain

1 performance on the other. However, with a proportion of performance not explained by a
2 running-based Yo-Yo IR1, it likely refers to the ability to perform distinct metabolically
3 demanding actions typical of collision sports. The results of this study have several practical
4 applications. Firstly, the increased metabolic, physiological and perceptual responses elicited
5 by adopting the prone position prior to accelerated running suggest this as a method that can
6 be used by coaches to modify training load within the periodized plan. This option might be
7 preferable for coaches in the lead up to match-play, enabling exposure to a high training load
8 without the added injury risk that might accompany collisions/tackles (Gabbett, Jenkins &
9 Abernethy, 2011). In addition, the test allows coaches to evaluate several determinants of
10 rugby specific performance for monitoring purposes over the season and to assess the efficacy
11 of specific training interventions. Future studies might wish to investigate the concurrent
12 validity of the prone Yo-Yo IR1 and its relationship to match performance. Furthermore, the
13 sensitivity of the prone Yo-Yo IR1 to detect a meaningful change in performance after a period
14 of training would be practically useful.

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12 Figure 1. Percentage difference in metabolic, physiological and
13 external responses measured for Yo-Yo IR1 and prone Yo-Yo
14 IR1 (bars indicated uncertainty in the true mean difference with
15 90% confidence intervals). Trivial areas were calculated from
16 the smallest worthwhile change.

17

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

22

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)	<i>Most likely</i> ↓
PlayerLoad™ (AU·min ⁻¹)	13.9 ± 0.9	14.6 ± 1.4	0.70 (0.27; 1.12)	<i>Very likely</i> ↑
High metabolic power (> 20W·kg ⁻¹ ·min ⁻¹)	3.5 ± 0.9	5.3 ± 1.2	1.80 (1.43; 2.07)	<i>Most likely</i> ↑
Acceleration 0-2 m/s (m·min ⁻¹)	6.2 ± 1.0	6.7 ± 1.6	1.10 (0.41; 1.73)	<i>Very likely</i> ↑
Acceleration 2-3 m/s (m·min ⁻¹)	6.0 ± 1.0	6.7 ± 0.5	0.62 (0.16; 1.08)	<i>Likely</i> ↑
Acceleration 3-4 m/s (m·min ⁻¹)	2.9 ± 0.5	3.5 ± 0.9	0.94 (0.47; 1.41)	<i>Very likely</i> ↑
Acceleration 4-20 m/s (m·min ⁻¹)	2.4 ± 0.6	3.0 ± 0.9	0.78 (0.36; 1.23)	<i>Very likely</i> ↑
Internal Responses				
HR _{peak} (b·min ⁻¹)	197 ± 8	195 ± 7	-0.26 (-0.51; -0.02)	<i>Possibly</i> ↓
Δ[La] _b (mmol·l ⁻¹)	9.2 ± 2.0	9.9 ± 1.2	0.36 (0.10; 0.72)	<i>Likely</i> ↑
RPE (AU)	17.1 ± 1.6	18.2 ± 1.5	0.63 (0.21; 1.04)	<i>Very likely</i> ↑
Ṁ _{Epeak} (L·min ⁻¹)	136.7 ± 33.4	144.3 ± 13.8	0.23 (-0.18; 0.64)	<i>Possibly</i> ↑
ṀO _{2peak} (mL·min ⁻¹ ·kg ⁻¹)	48.7 ± 3.8	50.2 ± 4.5	0.37 (-0.02; 0.76)	<i>Likely</i> ↑
ṀCO _{2peak} (L·min ⁻¹)	4.8 ± 0.37	4.9 ± 0.44	0.26 (-0.15; 0.68)	<i>Possibly</i> ↑

Note: Peak heart rate (HR_{peak}), delta blood lactate concentration Δ[La]_b, rating of perceived exertion (RPE), minute ventilation (Ṁ_{Epeak}), oxygen uptake (ṀO_{2peak}) and carbon dioxide production (ṀCO_{2peak}). ↑ = increase. ↓ decrease.

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

	160 m (<i>n</i> = 16)	280m (<i>n</i> = 16)	440 m (<i>n</i> = 15)
HR_{mean} ($b \cdot min^{-1}$)			
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	<i>Unclear</i>	<i>Unclear</i>	<i>Possibly ↓</i>
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	<i>Likely ↑</i>	<i>Very likely ↑</i>	<i>Most likely ↑</i>
\dot{V}_E ($L \cdot min^{-1}$)			
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	<i>Unclear</i>	<i>Most likely ↑</i>	<i>Most likely ↑</i>
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}$)			
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	<i>Unclear</i>	<i>Likely ↑</i>	<i>Very likely ↑</i>
$\dot{V}CO_2$ ($L \cdot min^{-1}$)			
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	<i>Unclear</i>	<i>Most likely ↑</i>	<i>Very likely ↑</i>

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.

