Convergent validity and reliability of a novel repeated agility protocol in junior rugby league players [version 1; peer review: 2 approved with reservations]

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Abstract

Background: Rugby league involves repeated, complex, change-of-direction movements, although there are no test protocols that specifically assess these physical fitness profiles. Thus, the current study examined the convergent validity and reliability of a repeated Illinois Agility (RIA) protocol in adolescent Rugby League players.

Methods: Twenty-two junior Rugby League players completed 4 sessions with each separated by 7 days. Initially, physical fitness characteristics at baseline (i.e., multi-stage fitness, countermovement jump, 30-m sprint, single-effort agility and repeated sprint ability [RSA]) were assessed. The second session involved a familiarisation of RIA and repeated T-agility test (RTT) protocols. During the third and fourth sessions, participants completed the RIA and RTT protocols in a randomised, counterbalanced design to examine the validity and test-retest reliability of these protocols.

Results: For convergent validity, significant correlations were identified between RIA and RTT performances (r = >0.80; p<0.05). For contributors to RIA performance, significant correlations were identified between all baseline fitness characteristics and RIA (r = >0.71; p < 0.05). Reliability of the RIA protocol was near perfect with excellent intra-class correlation coefficient (0.87-0.97), good ratio limits of agreement (×/÷ 1.05-1.06) and low coefficient of variations (1.77-1.97%).

Conclusions: The current study has demonstrated the RIA to be a simple, valid and reliable field test that can provide coaches with information about their athlete's ability to sustain high intensity, multi-directional running efforts.

Keywords
Change of direction, anaerobic power, sprint, speed, recovery rate
Introduction

Rugby League (RL) is an intermittent, invasion type game that requires players to complete repetitive bursts of sprinting and multi-directional movements in response to the dynamic constraints of the game, typically referred to as ‘agility’ movements. Traditionally, the physical component of agility has been assessed using change-of-direction routes with shorter time of completion considered a strong determinant of agility performance. Some commonly used agility tests have included the Agility T-Test and the Illinois Agility test with both employed in many intermittent sports. However, these two assessment protocols employ a single bout approach for the agility performance measure. Athletes in RL encounter repeated bursts of change-of-direction movements to defend or evade defenders during a game. Consequently, performance of repeated agility activities with brief periods of rest may be an important performance component necessary for RL athletes.

As a monitoring tool, the reliability of repeated agility protocols have been explored in a variety of sports. Results from a study examining a Repeated T-Test (RTT) agility protocol in soccer players significantly correlated with anaerobic measures of power, speed and repeat-sprint ability (RSA), with excellent test-retest reliability. While a good indicator of agility, the Agility T-Test consists of a linear sprint, lateral shuffles and a backwards run, which are movements that are sporadic in RL. In fact, RL players change direction frequently and utilise evading movements that are not replicated by the Agility T-Test. Therefore, the Illinois Agility test may be more reflective of the evading activities undertaken in RL, as the protocol includes vigorous changes in direction by weaving in and out of cones. As the validity and reliability of the Repeated Illinois Agility (RIA) test have yet to be determined, reporting these properties would be essential for widespread usability.

The aims of this study were three-fold: 1) to examine the convergent validity of a novel RIA test with the repeated Agility T-test protocol (i.e. RTT); 2) to identify contributors of RIA performance by comparing its measures to speed, anaerobic capacity and recovery dynamics (i.e. RSA); and 3) to determine the test-retest reliability of the RIA protocol. It was hypothesised that the RIA would demonstrate acceptable convergent validity and reliability as a repeated agility test, with relationships identified between results of the RIA and the RTT, speed, and anaerobic capacity protocols. Identification of the convergent validity and reliability of the RIA will provide coaches with a tool to assist in monitoring and training RL athletes as well as in talent development and identification.

Methods

Research design

The current study was a randomised, counter-balanced study conducted across five sessions from June, 2018 to August, 2018 (Figure 1). During the first session, the participants completed a Multistage Shuttle test to determine predicted maximal aerobic capacity (VO₂max)10. The second session was utilised to obtain baseline assessments of speed (30-metre sprint), agility (Illinois Agility test, Agility T-Test) and repeat-sprint ability (RSA). The third session familiarised participants with the RTT and RIA tests. During the fourth and fifth sessions, participants undertook both the RIA and RTT, in randomised order, with at least 15-minutes of recovery between each protocol.

At the start of each session, muscle soreness rating was collected prior to performing a standardised warm up, using a 1-10 visual analogue scale, with 1 and 10 indicating ‘no soreness’ and ‘very, very sore’11. Participants then performed a progressive warm-up consisting of jogging for 3–5 minutes and 15-metre sprints at 50%, 70% and 100% of maximal effort. A countermovement jump (CMJ) test (Yard Stick, Swift Performance, Queensland, Australia) was then conducted to assess leg power12, which was also repeated before the second agility test to confirm recovery between the repeated agility tests.

Participants

In total, 22 adolescent, male, RL players (age 16.2 ± 0.8 yrs; body mass 80.7 ± 16.3 kg; height 1.77 ± 0.7 m) who engaged in the School of Athletic Excellence program were recruited via word of mouth, flyers and liaison with sporting teams. The participants were injury-free with at least 2 years of RL experience. According to an a priori calculation, a sample size of 22 was sufficient to identify significant differences in repeated-agility...
performance (power of 80%, alpha level of 0.05). Participants were instructed to avoid strenuous physical activity and caffeine for up to 12 hours before each testing session. All protocols were approved by the Institutional Human Research Ethics Committee and written informed consent was received from the participants and their parents/guardians prior to partaking this study (Approval number H7248).

Multistage shuttle test
For the multistage shuttle test, participants ran back and forth in time with a series of audio signals on a 20m indoor court. The time between audio signals progressively decreased during the test resulting in an increased effort and running speed for athletes each minute. Predicted VO\textsubscript{2max} was estimated using a previously developed regression equation.

Countermovement jump test
The countermovement jump protocol was measured with a vertical jump apparatus, based on 1 cm increments (Yard Stick, Swift Performance, Queensland, Australia). To ensure standardisation of the countermovement jump test, participants were instructed to draw their arms backwards upon the eccentric phase, then swing the arms forward during the concentric phase to gain momentum and maximise the stretch-shortening cycle mechanics. The participants attempted three countermovement jumps, with approximately 30–60 seconds of rest in-between, and the highest jump reported.

30-m Sprint and Agility protocols
Assessment of speed was achieved by completing 30-m maximal sprints, the Agility T-test protocol was set up within a 10-m × 10-m figure-T course (Figure 2A), and the Illinois Agility protocol consisted of a 10m × 5m course (Figure 2B). To ensure protocol familiarity, the participants completed three trials at sub-maximal effort followed by one final maximal trial, with each trial interspersed by two minutes of recovery. Trial completion times were recorded using an electronic timing gate system (Speedlight Timing Gates, Swift Performance, Australia) positioned at the start/finish line. The fastest time was used for later analysis.

Repeat Sprint and Agility Protocols
The RSA, RTT and RIA protocols were completed by repeating the previously described protocols (i.e. 30-m sprint, T-test and Illinois Agility, respectively) across 6 cycles with varying recovery periods in-between each cycle. Specifically, each cycle within the RSA, RTT and RIA was separated by 20-, 35- and 60-second recovery, respectively, with work-to-rest ratios of approximately 1:3. Immediately after each repeated agility cycle, participants’ heart rate (HR, Polar

![Figure 2](image-url)
Heart Rate Monitor, Polar H10, Finland) and maximum rating of perceived-exertion (RPE, Borg category scale 1–10) were then averaged across the 6 cycles for analysis\(^8\). The following parameters were also calculated for each repeated agility protocol: total time (TT) of 6 cycles, best cycle time (BT), the average cycle time (AT) and fatigue index (FI)\(^4\). FI was calculated as follows:\(^8\):

\[
\text{Fatigue Index} = \left( \frac{\text{TT}}{\text{BT} \times 6} \times 100 \right) - 100
\]

**Statistical analysis**

Data was analysed using a statistical software (IBM SPSS version 25, Chicago, Illinois) and reported as mean ± standard deviation. Normality of the data was assessed using the Kolmogorov-Smirnov statistic. Convergent validity of the repeated agility protocols was identified via Pearson’s product moment correlation coefficients for RTT and RIA measures (i.e., TT, BT, AT and FI) and construct validity with aerobic capacity, leg power, speed and agility variables (i.e., VO\(_{2\max}\), CMJ, 30-m sprint time, T-Test and Illinois Agility, respectively). The cut-off for acceptable convergent validity was established when the association was statistically significant with an r-value of ≥ 0.50\(^\text{9}\). Reliability of the repeated agility measures was determined via a paired T-test, intraclass correlation coefficients (ICC, SPSS 2-way mixed, 95% confidence intervals), coefficient of variation (CV, 95% confidence intervals) and systematic bias/ratio with 95% limits of agreement (LOA)\(^7\). Where significant relationships existed between the mean difference and average of test-retest values (i.e. heteroscedastic errors), variables were transformed (natural logarithm) prior to the calculation of measurement bias/ratio ÷ ratio LOA\(^8\). The level of significance for all analyses was set at 0.05. Finally, effect size (Cohen’s \(d\)) with 95% CI was used to calculate the magnitude of differences in muscle soreness and CMJ measures between RIA and RTT protocols to determine whether the recovery periods were appropriate. The ES classifications were set as small, moderate and large with values of 0.2, 0.5 and 0.8, respectively (Cohen, 1988).

**Results**

For convergent validity, significant correlations were identified between RIA and most RTT variables (Table 1\(^\text{9}\)). For contributors to RIA performance, significant correlations were identified with RSA, 30-m sprint time, best effort agility measures, aerobic capacity and CMJ (Table 2\(^\text{9}\)).

Muscle soreness ratings between the third (2.0 ± 1.5) and fourth (2.6 ± 1.7) were not significantly different (\(p = 0.10\)), with a small ES (0.37). Jump height prior to each repeated agility protocol remained unchanged between the first and second CMJ tests in the third (43.8cm ± 8.7cm and 45.4cm ± 8.4cm, respectively, \(p = 0.09\)) and fourth (44.1cm ± 9.3cm and 44.0cm ± 8.6cm, respectively, \(p=0.80\)) session, also with small ES (0.19 and 0.01, respectively).

All RIA measures were similar between sessions except for FI and maximum RPE (Table 3\(^\text{9}\)). Most RIA performance measures exhibited excellent test-retest reliability (ICC = 0.92–0.97), good levels of agreement (ratio LOA = 1.05–1.06) and low measurement error (CV = 2.17–2.68%, Table 3\(^\text{9}\)). However, FI and average RPE demonstrated moderate test-retest reliability (ICC = 0.87 and 0.76, respectively), poorer levels of agreement (ratio LOA = 2.57 and 2.23, respectively) and higher measurement error (CV = 25.3 and 15.8%, respectively, Table 3\(^\text{9}\)).

For the RTT, excellent test-retest reliability (ICC = 0.91), good levels of agreement (ratio LOA = 1.08) and low measurement error (CV = 2.17–2.68%) were identified for a few variables (Table 3\(^\text{9}\)). However, high test-retest reliability (ICC = 0.93), lower levels of agreement (ratio LOA = 1.78) and higher levels of measurement error (CV = 12.3%) were observed for

**Table 1. Relationship between performance measures of the repeated Illinois agility test (RIA), repeated T-agility test (RTT) and repeated sprint ability (RSA).**

<table>
<thead>
<tr>
<th></th>
<th>RIA</th>
<th>RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TT (s)</td>
<td>BT (s)</td>
</tr>
<tr>
<td>RTT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT (s)</td>
<td>0.84***</td>
<td>0.81***</td>
</tr>
<tr>
<td>BT (s)</td>
<td>0.81***</td>
<td>0.81***</td>
</tr>
<tr>
<td>AT (s)</td>
<td>0.84***</td>
<td>0.80***</td>
</tr>
<tr>
<td>FI (%)</td>
<td>0.43**</td>
<td>0.32</td>
</tr>
<tr>
<td>RSA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT (s)</td>
<td>0.80***</td>
<td>0.73***</td>
</tr>
<tr>
<td>BT (s)</td>
<td>0.63***</td>
<td>0.51***</td>
</tr>
<tr>
<td>AT (s)</td>
<td>0.80***</td>
<td>0.73***</td>
</tr>
<tr>
<td>FI (%)</td>
<td>0.48**</td>
<td>0.61***</td>
</tr>
</tbody>
</table>

\(\text{TT} = \) total time; \(\text{BT} = \) best time; \(\text{AT} = \) average time; \(\text{FI} = \) fatigue index

* \(P<0.05 \)** \(P<0.01 \)** ** \(P<0.001\)
Table 2. Pearson correlation coefficients between repeated performances, perceptual and physiological indices (repeated Illinois agility [RIA], repeated T-agility test [RTT]) with aerobic capacity, leg power, speed, and agility test performance measures.

<table>
<thead>
<tr>
<th></th>
<th>VO_2max (mL·kg⁻¹·min⁻¹)</th>
<th>CMJ (cm)</th>
<th>Sprint 30m (sec)</th>
<th>IA (sec)</th>
<th>TTA (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT (s)</td>
<td>-0.73**</td>
<td>-0.85**</td>
<td>0.89**</td>
<td>0.87**</td>
<td>0.72**</td>
</tr>
<tr>
<td>BT (s)</td>
<td>-0.71**</td>
<td>-0.79**</td>
<td>0.81**</td>
<td>0.86**</td>
<td>0.71**</td>
</tr>
<tr>
<td>AT (s)</td>
<td>-0.73**</td>
<td>-0.85**</td>
<td>0.89**</td>
<td>0.87**</td>
<td>0.72**</td>
</tr>
<tr>
<td>FI (%)</td>
<td>-0.43*</td>
<td>-0.57**</td>
<td>0.61**</td>
<td>0.49^</td>
<td>0.40</td>
</tr>
<tr>
<td>HR_avg</td>
<td>-0.43</td>
<td>-0.09</td>
<td>0.34</td>
<td>0.24</td>
<td>0.38</td>
</tr>
<tr>
<td>HR_max</td>
<td>-0.20</td>
<td>-0.03</td>
<td>0.12</td>
<td>0.04</td>
<td>0.21</td>
</tr>
<tr>
<td>RPE_avg</td>
<td>0.17</td>
<td>0.17</td>
<td>-0.21</td>
<td>-0.16</td>
<td>-0.21</td>
</tr>
<tr>
<td>RPE_max</td>
<td>-0.04</td>
<td>-0.23</td>
<td>0.27</td>
<td>0.35</td>
<td>0.21</td>
</tr>
<tr>
<td>RTT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT (s)</td>
<td>-0.68**</td>
<td>-0.76**</td>
<td>0.80**</td>
<td>0.84**</td>
<td>0.80**</td>
</tr>
<tr>
<td>BT (s)</td>
<td>-0.65**</td>
<td>-0.74**</td>
<td>0.80**</td>
<td>0.86**</td>
<td>0.85**</td>
</tr>
<tr>
<td>AT (s)</td>
<td>-0.68**</td>
<td>-0.76**</td>
<td>0.80**</td>
<td>0.84**</td>
<td>0.80**</td>
</tr>
<tr>
<td>FI (%)</td>
<td>-0.41</td>
<td>-0.37</td>
<td>0.34</td>
<td>0.28</td>
<td>0.14</td>
</tr>
<tr>
<td>HR_avg</td>
<td>-0.41</td>
<td>-0.05</td>
<td>0.26</td>
<td>0.13</td>
<td>0.23</td>
</tr>
<tr>
<td>HR_max</td>
<td>-0.33</td>
<td>-0.68</td>
<td>0.21</td>
<td>0.06</td>
<td>0.24</td>
</tr>
<tr>
<td>RPE_avg</td>
<td>0.00</td>
<td>0.02</td>
<td>-0.03</td>
<td>0.02</td>
<td>-0.07</td>
</tr>
<tr>
<td>RPE_max</td>
<td>0.02</td>
<td>0.04</td>
<td>-0.03</td>
<td>0.03</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

CMJ = countermovement jump; TT = total time; BT = best time; AT = average time; FI = fatigue index; Sprint 30m = 30 metre sprint; IA = Illinois Agility test; TTA = T-test agility; VO_2max = maximal aerobic capacity; RPE_avg = Average Rate of Perceived Exertion, RPE_max = Maximum Rate of Perceived Exertion, HR_avg = Heart rate average, HR_max = Maximum heart rate.*P<0.05  **P<0.01  ***P<0.001

maximum RPE (Table 3). In addition, FI, average RPE and maximum HR displayed moderate to large reliability (ICC = 0.69 – 0.89), poorer agreement (ratio LOA = 1.10 – 2.59) and higher measurement error (CV = 2.38 – 27.6%) compared to the RIA protocol (Table 3).

Discussion
The current findings demonstrated strong correlations between the RIA and RTT protocols, specifically the BT, TT and AT measures. These results highlight that most time-derived measures (i.e., BT, TT and AT measures) of the RIA are replicable to a previously established repeated agility protocol, but with movement demands more representative of RL. In addition, the TT and BT of the RIA was strongly associated with the TT and BT of the RSA, indicating that the ability to maintain linear speed would result in superior performances in the RIA protocol, possibly due to similar metabolic demands. Comparable findings were reported by Fessi, Makni, with strong correlations identified between the BT and TT of their repeated agility protocol and RSA protocols in 4S team-sport athletes. Collectively, our results and others, suggest that performance of repeated agility relies heavily upon the anaerobic system, a metabolic pathway predominant in RL.

The current study also identified strong test-retest reliability for time-derived measures (i.e., BT, TT and AT) of the RIA, with minimal measurement error. However, the measurement error was substantially higher for FI, confirming previous studies that reported substantially stronger reliability measures for BT, TT and AT compared to that of FI from various repeated agility protocols. It has been suggested that FI may exhibit weaker reproducibility as the measure is multi-faceted and dependent on the stability of other variables (i.e., TT and BT). Subsequently, we, and others, recommend that time-derived measures be primarily evaluated during repeated agility protocols.

Another novelty of the current study was the reliability of the psychophysiological responses during both RIA and RTT protocols. The test-retest reliability values for HR and RPE ranged between questionable-to-excellent classifications according to ICC scores for both RIA and RTT. However, distinctly
greater measurement error and bias was observed for RPE when compared to HR measures for both RIA and RTT. These findings were similar to previous studies with poorer reliability for RPE than HR measures during various running protocols\textsuperscript{3,29-31}. It has been postulated that HR has better stability across days given that it is an objective measure, compared to the highly subjective RPE\textsuperscript{30}. It has also been reported that participant’s prior knowledge of the number of sprints during repeated sprint-type protocols may affect results due to pacing\textsuperscript{37}. Accordingly, HR measures may be a better physiological indicator for monitoring exercise-induced stress during repeated agility protocols.

An additional, yet essential finding of this study was the relationship between baseline characteristics and performances measured from the repeated agility tests. Measures of CMJ, best-effort speed and best-effort agility correlated significantly with the time-derived variables of the RIA. These relationships indicated that lower limb power, linear speed and change-of-direction ability were contributing factors to successful repeated agility performances and key attributes needed for RL athletes\textsuperscript{19}.

Our findings aligned with those of Haj-Sassi, Dardouri\textsuperscript{1}, who reported strong correlations between measures of jump performance and repeated agility performance with an Agility T-test protocol. These authors suggested that larger jumping performances reflected athlete’s superior ability to generate force into the ground and therefore a significantly greater change-of-direction ability\textsuperscript{4}. The significance of this finding attests to lower limb power production being a critical component of repeated agility performance, especially within the RIA.

Finally, the current study identified significant correlations between VO\textsubscript{max} and RIA performance measures. These findings are similar to previous studies using various repeated agility protocols\textsuperscript{1,2,12} as well as RSA protocols\textsuperscript{29-31}. Measures of VO\textsubscript{max} has been considered essential for repeated-sprint type protocols, due to muscular reoxygenation rate\textsuperscript{24}, optimal capacity to remove and buffer hydrogen ions within working muscles\textsuperscript{35} and efficiently replenish phosphagen stores\textsuperscript{34}. The findings of the present study suggest that aerobic capacity is a strong contributor to superior repeated agility efforts, further highlighting

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### Table 3. Test-retest results, intra-class correlation coefficients (ICC, 95% confidence interval (CI)), measurement bias/ratio (log-transformed data) (×/÷ 95% ratio limits of agreement (ratio-LOA)) and within-subject coefficient of variation (95% CI) of the repeated Illinois Agility (RIA) and T-test (RTT) protocol.

<table>
<thead>
<tr>
<th>Test</th>
<th>RIA</th>
<th>Retest</th>
<th>p</th>
<th>ICC (95% CI)</th>
<th>CV% (95% CI)</th>
<th>Bias ratio-LOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT (s)</td>
<td>108.22 ± 9.14</td>
<td>107.38 ± 8.39</td>
<td>0.23</td>
<td>0.97 (0.92 - 0.99)***</td>
<td>1.97 (0.91-2.16)</td>
<td>1.01 ± 1.06</td>
</tr>
<tr>
<td>BT (s)</td>
<td>17.00 ± 1.03</td>
<td>17.05 ± 1.05</td>
<td>0.60</td>
<td>0.96 (0.90 - 0.98)***</td>
<td>1.77 (0.98-1.83)</td>
<td>1.00 ± 1.05</td>
</tr>
<tr>
<td>AT (s)</td>
<td>18.04 ± 1.52</td>
<td>17.90 ± 1.40</td>
<td>0.61</td>
<td>0.98 (0.97 - 0.99)***</td>
<td>1.97 (0.91-2.16)</td>
<td>1.01 ± 1.06</td>
</tr>
<tr>
<td>FI (%)</td>
<td>6.02 ± 3.50</td>
<td>4.91 ± 3.18</td>
<td>0.03†</td>
<td>0.87 (0.68 - 0.95)***</td>
<td>25.3 (22.9-40.1)</td>
<td>1.32 ± 2.57</td>
</tr>
<tr>
<td>RPE\textsubscript{avg}</td>
<td>4.9 ± 1.2</td>
<td>4.3 ± 1.7</td>
<td>0.07</td>
<td>0.76 (0.41-0.90)**</td>
<td>15.8 (6.1-25.6)</td>
<td>1.20 ± 2.23</td>
</tr>
<tr>
<td>RPE\textsubscript{max}</td>
<td>6.5 ± 1.6</td>
<td>6.1 ± 1.7</td>
<td>0.04†</td>
<td>0.93 (0.83-0.97)***</td>
<td>8.1 (4.8-11.7)</td>
<td>1.08 ± 1.34</td>
</tr>
<tr>
<td>HR\textsubscript{avg} (bpm)</td>
<td>183.8 ± 8.5</td>
<td>180.2 ± 10.2</td>
<td>0.09</td>
<td>0.92 (0.89-0.97)***</td>
<td>2.10 (1.48-2.72)</td>
<td>1.02 ± 1.06</td>
</tr>
<tr>
<td>HR\textsubscript{max} (bpm)</td>
<td>189.0 ± 8.3</td>
<td>188.3 ± 9.6</td>
<td>0.53</td>
<td>0.94 (0.83-0.98)***</td>
<td>1.31 (0.78-1.84)</td>
<td>1.00 ± 1.05</td>
</tr>
</tbody>
</table>

Test (s): total time; BT = best time; AT = average time; FI = fatigue index, RPE = Average Rate of Perceived Exertion, RPE\textsubscript{max} = Maximum Rate of Perceived Exertion, HR\textsubscript{avg} = Heart rate average, HR\textsubscript{max} = Maximum heart rate *P<0.05 **P<0.01 ***P<0.001

† Significantly different (p<0.05)
the need to optimise recovery capacities between high-intensity bouts for RL athletes.

In conclusion, the RIA protocol exhibited moderate-to-excellent test-retest reliability and low measurement error for the majority of time-derived measures and psychophysiological measures, and questionable reliability for FI. Further, this study has clearly demonstrated that repeated agility performances rely upon contributions from both anaerobic and aerobic systems with the RIA, demonstrating that the qualities required for optimal RIA performance may be representative of the physical demands in RL. The RIA protocol may provide practitioners with a simple, yet effective monitoring tool to quantify athlete’s ability to generate and sustain multi-directional efforts, and their ability to recover during intermittent activities.

**Data availability**

**Underlying data**

James Cook University Research Data: Convergent validity and reliability of a novel repeated agility protocol in junior rugby league players. [https://doi.org/10.25903/5eb0f568fad20](https://doi.org/10.25903/5eb0f568fad20)

This project contains the following underlying data:

- Raw_data_De-identified.xlsx (Agility protocol data in excel format)
- Raw_data_De-identified.ods (Agility protocol data in ods format)

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

**References**

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27. Billaut F, Bishop DJ, Schaeer S, et al.: Influence of knowledge of sprint number...


Open Peer Review

Current Peer Review Status: ? ?

Version 1

Reviewer Report 03 August 2021

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Thank you for the opportunity to review this manuscript. A logical study with potential practical impact was presented exploring the validity and reliability of a repeated change-of-direction speed test suited to rugby league. This aspect of fitness testing is lacking in the literature and of use for end-users, so this manuscript has merit for publication. I do however have some suggestions and queries listed below that will help strengthen some aspects of the work that should be addressed by the authors:

1. Abstract, Methods – indicate whether you are referring to the multi-stage fitness test (i.e., Beep test) here or if just an assessment of multi-stage fitness was performed.

2. Abstract – some justification of using the repeated T-agility test as the other standard repeated change-of-direction performance to assess convergent agility of the repeated Illinois Agility test is needed in the Abstract.

3. Abstract – the focus of exploring the contribution of different fitness attributes to repeated Illinois Agility test performance is not made in the Abstract. Consider including this as a secondary objective and/or making it clear why this analysis is needed.

4. Abstract, Conclusions – make it clear that this test is useful for Rugby League coaches specifically, and change “athlete” to plural form or indicate “team” here instead.

5. Introduction, opening paragraph – in this paragraph you identify “agility” and hint that it involves physical and cognitive components. So in essence, you are examining change-of-direction speed (the physical component) rather than “agility” per se. Consider making this clear and using the term “change-of-direction speed” or “change-of-direction performance” thereafter when referring to tests and attributes that are purely physical without the cognitive component.

6. Introduction, opening paragraph – stronger rationale is needed justifying the inclusion of
the Agility T-test and Illinois Agility test in rugby league. Can you add a sentence or two outlining why these tests are suited to the sport and therefore the focus of your study?

7. Introduction, end of second paragraph – here indicate whether the validity and reliability of this test has not been investigated at all or just specifically in Rugby League athletes. Also, at the end of this sentence make it clear that you are referring to the usability of this test.

8. Introduction, aims – for the second aim, you are not comparing the RIA measures to other measures, but instead correlating them, so please change this aim accordingly. Also, consider including a little rationale around this aim in the previous paragraph as it is unclear as to why this is important.

9. Introduction, aims – it might pay to include a sentence stating why examining convergent validity (e.g. to show that you are assessing similar attributes with a new test that is more practical and specific to Rugby League when compared to a standard, generic test routinely used) and retest reliability (e.g. to detect the inherent error in the test and ascertain whether it can be reliably adopted in practice to assess repeated measurements in athletes) are needed for practical uptake of the test, which would strengthen the rationale of the first and third aims as well in the Introduction section.

10. Introduction, hypotheses – you only mention speed and anaerobic capacity as your fitness attributes here, but you also included aerobic fitness (Multistage Fitness test)?

11. Methods, Research design – why was the order flipped between session 4 and session 5? It seems like you would want to the athletes to complete the same exact session across both when assessing retest reliability as it is introducing a confounding factor? Also, no hyphen needed between “15” and “minutes” here.

12. Methods, Participants – can you provide some further indication as to the specific playing level of the athletes? The name of the program is great, but this is not exactly clear for all readers.

13. Figure 1 – consider changing the session numbers, as in text you identify the Multistage Fitness test as session 1, but here you indicate the other fitness testing as session 1. Consistency needed.


15. Methods, Multistage Shuttle test – stay consistent with capitalising the test names like this one as it is done inconsistently throughout. Also, hyphenate “20m” here.

16. Methods, Countermovement jump test – hyphenate “1 cm” here. Also, try to indicate what units the key outcomes from each test were reported in (e.g. mL/kg/min, cm, s).

17. Methods, 30-m Sprint and Agility protocols – separate statements on linear and change-of-direction speed here. Also, hyphenate “10m” and “5m” for the Illinois Agility test.
18. Methods, repeat protocols – to calculate average HR and RPE, was HR measured from when the test started to when the test finished in 1-second intervals? And was RPE taken after each effort or just after all efforts for each specific test? These are not quite clear.

19. Methods, Statistical analysis – you mention “construct” validity for the first time here. If this is a key aim and aspect of the study (i.e., correlating performance during the test with fitness attributes), then this needs to be established earlier (i.e., introduction and aims).

20. Methods, Statistical analysis – an r value of 0.5 seems quite low to establish convergent validity (only 25% shared variance)? In this regard, what was the cut-off for construct validity?

21. Results, first paragraph – clarify whether this is CMJ height specifically.

22. Results, second paragraph – make it clear that you are referring to the third and fourth sessions here (and make sure this is consistent as you identify these as the fourth and fifth sessions earlier).

23. Results, third paragraph – you do not indicate the maximum RPE was taken as an outcome in the methods anywhere (only average), yet it is listed here? Same for maximum HR, which appears later in this section also.

24. Table 1 – shouldn't RIA and RTT be the two key tests going from left to right rather than RIA and RSA? In fact, it is not clear why RSA is included here given you identify RIA vs. RTT for convergent validity assessment throughout the manuscript. Please adjust or rework earlier sections.

25. Discussion, first paragraph – some minor errors, but change “was” to “were” in the 7th line.

26. Discussion, first paragraph – at the end of this paragraph, some explanation as to how yours (and the previous studies) support that anaerobic fitness is predominantly stressed in the repeated COD tests. I am assuming the strong correlations with mostly anaerobic fitness attributes, but this is an assumption and should be explained further to clarify this statement.

27. Discussion, fourth paragraph – be careful with your statement suggesting they are “key attributes for RL athletes”. You did not show this but state it, so rework or remove this part to focus specifically on what your data show.

28. Discussion, concluding paragraph – here you highlight how anaerobic and aerobic fitness underpin test performance, but previously you focus on anaerobic fitness in other sections and in this section. Please make sure the message is consistent throughout.

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Is the work clearly and accurately presented and does it cite the current literature?  
Yes

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?  
Yes

If applicable, is the statistical analysis and its interpretation appropriate?  
Yes

Are all the source data underlying the results available to ensure full reproducibility?  
Yes

Are the conclusions drawn adequately supported by the results?  
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Exercise and sport science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
I do think that the authors have a publishable study here, however, a number of revisions will be required before I would be happy to approve this manuscript for indexing. I hope that my comments are received as I intend them and are useful in further strengthening this manuscript. I hope to receive the opportunity to review this manuscript again in its revised form.

**Abstract**
The abstract is concise and accurate to the details of the study. I have just a couple of minor comments (below):
The initial sentence is accurate and outlines the requirement of the study. However, I would encourage the authors to insert a word such as ‘simultaneously’ or ‘congruently’, or attempt to capture the lack of a suitable test to capture the performance of these abilities in combination.

**Abstract Methods** – the inclusion of the repeated T-agility test appears suddenly with no prior reference. If this is a key concentration of your study, I would encourage to insert earlier in the abstract along with the RIA.

**Abstract Results** – please specify exact p values rather than just <0.05. CV% can be presented to 1dp for brevity.

**Introduction**
The introduction is short and concise. However, I feel some key information that would further support the rationale for your study has been omitted. I would encourage the authors to further develop this section. A suggestion would be to expand the second paragraph into two: the first discussing the validity aspects, the second the reliability aspects. I do not expect these changes to be too onerous, but believe it would strengthen this section of your manuscript if you were to implement these changes. I have some further specific comments below.

The opening sentence would read better if it were split into two separate sentences.

The authors should attempt to clarify during opening paragraph that they are discussing change of direction (COD) performance, rather than agility. Although COD performance is a key component of agility performance, the lack of an external stimuli prevents classification of agility. Although the tests identified by the authors in this opening paragraph have titled themselves ‘agility’ tests, by definition they are not. The authors should be careful in their stance here as the literature has evolved substantially since the inception of tests such as these, and appropriate classification and terminology is essential for the present study.


Regarding the reliability aspect of the study, two recent papers have suggested that reliability of COD and agility may be lower in adolescent and youth athletes (as per your sample). Although these authors observed this during maximal COD/agility performance, opposed to repeated as in the present study, I believe this would be worth including and would further warrant the exploration of your research question and study.

Methods
The methods report the appropriate details relating to the study design, protocols, participants, and analyses performed. However, further clarity is required in a few places throughout this section (specific comments below). Further, there are a number of oversights throughout this section that require careful attention. None of these are major points, and should take little time to amend. Yet, need to be addressed prior to potential resubmissions of this manuscript.

Figure 1: I am unsure how much this figure aids the interpretation of the study design. I personally do not feel the visual nature of this schematic clarifies the description of the trials from the text, as the study is relatively simplistic. I do not insist that the authors remove this figure, however, please consider my suggestion that it may not add value to the manuscript and may just be a “figure for the sake of a figure”. Secondly, between the trials, the authors have stated that washout periods of >7 days were implemented. The authors should consider including the range of days (e.g. 7-14 days), as this would provide further information to the reader and allow for more accurate interpretation of the results.
Can a citation or elaboration be provided to rationalise the >15 min rest interval between attempts?
The term ‘respectively’ needs to be included after the explanation of the 1-10 muscle rating scale. Also, a brief sentence as to why this was collected should accompany this methodological point.
The authors state that the warm up was the same prior to each session. I would encourage using the term ‘standardised’ when describing this in their methods to add certainty around their controls. Also, a citation needs to accompany the statement that the CMJ test was implemented to assess recovery. If this is what was intended by the insertion of citation 12, I would encourage moving this citation to the end of the sentence.
Participant details – participant height needs to be reported to 2dp. Can the authors further elaborate on what the “School of Athletic Excellence” is? For example, what standard is this, is it affiliated to a specific school, or region performance programme? This may not be clear to readers.
Multistage shuttle test – a brief sentence stating how performance or a score was derived is necessary (i.e. maximum number of shuttles completed, level, etc.). This information is currently not evident.
CMJ – please state the unit of measurement for this test, and to what degree (e.g. recorded in cm to the nearest 0.1cm).
30-m sprint and agility protocols – please separate each test into a separate sentence. At present, they appear too cramped together and it is difficult to read (particularly with reference to figures and citations within). Also, please provide citations for the original studies for the T-drill and Illinois agility tests. These need to be credited within the manuscript.
Repeated sprint and agility protocols – were these tests performed one after the other (what I interpret from the term ‘cycles’) or were they performed independently? Clarity is required to ensure the reader understands which of these interpretations is correct.
The sentence starting “Immediately after each repeated agility cycle...” does not make sense. Please rephrase this.
Statistical analysis – Reference 16 seems a weak reference for this point. I encourage the authors
to consider a more suitable citation for selecting this acceptable correlation cut off point.

**Results**
The section of the results dedicated to the muscle soreness and CMJ differences (or lack thereof) should be condensed to a singular sentence and placed at the foot of the results section. This is a methodological control and not a key finding from your study, therefore, it should not feature so early and heavily within your results section. Stating that there were no differences, providing ES, and significance values would suffice.

Table 3 – I am interested in your rationale for not providing ES to demonstrate differences (or lack thereof) for your test-retest data? This would add value in my opinion. I would also encourage the authors to present CV% data to 1dp both within this table and throughout the manuscript.

I notice that the authors use terminology such as “excellent” or “moderate” test-retest reliability, yet they have not included these threshold within the statistical analysis section of the methods. Please include this detail so that the reader understands your criteria.

I also note that the authors say “most RIA performance measures exhibited excellent test-retest reliability...”. Could the authors rephrase this to say “all RIA performance measures except... measures exhibited excellent test-retest reliability”? This would be more accurate and less ambiguous for the reader. This comment also applies later in this section where the authors refer to “a few variables...”.

**Discussion**
I found the discussion well-written and thought the authors accurately interpreted and attempted to explain their findings. However, similar to the introduction, I felt this section lacked depth when discussing the main findings of the study. I encourage the authors to discuss their findings in greater depth, utilising some of the reading attached to this review.

I encourage the authors to utilise the first paragraph of the discussion to summarise all of their main findings, and then progress to discussing each point in turn.

The third paragraph begins “another novelty of this study”, yet this appears to be the first time novelty is addressed in the discussion?

The fourth paragraph can draw upon a wealth of correlational studies to further support the findings observed here.


The conclusion should be reframed around the key objectives of the study (i.e. that it is reliable and valid). The mention of aerobic and anaerobic energy systems seems misplaced here.

**References**
While a variety of key texts are identified and listed within the bibliography and cited throughout the manuscript, a number of key texts are omitted. I encourage the authors to further familiarise themselves with relevant studies assessing reliability and validity of COD and agility in team sport athletes, as well as the texts identified earlier within this review.


References

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Yes
Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Fitness testing; youth athletes; talent identification; talent development; physical performance; strength and conditioning

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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