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

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28 **ABSTRACT**

29 This study investigated the concurrent validity of a rugby-specific high-intensity intermittent
30 running test (HIIR) against the internal, external and perceptual responses to simulated match-
31 play. Thirty-six rugby league players (age 18.5 ± 1.8 years; stature 181.4 ± 7.6 cm; body mass
32 83.5 ± 9.8 kg) completed the prone Yo-Yo IR1, of which sixteen also completed the Yo-Yo
33 IR1, and 2 x ~20 min bouts of a simulated match-play (RLMSP-i). *Most likely* reductions in
34 relative total, low-speed and high-speed distance, mean speed and time above $20 \text{ W}\cdot\text{kg}^{-1}$
35 (HMP) were observed between bouts of the RLMSP-i. Likewise, rating of perceived exertion
36 (RPE) and percentage of peak heart rate ($\%HR_{\text{peak}}$) were *very likely* and *likely* higher during
37 the second bout. Pearson's correlations revealed a *large* relationship for the change in relative
38 distance ($r = 0.57\text{-}0.61$) between bouts with both Yo-Yo IR1 tests. The prone Yo-Yo IR1 was
39 more strongly related to the RLMSP-i for change in repeated sprint speed ($r = 0.78$ *cf.* 0.56),
40 mean speed ($r = 0.64$ *cf.* 0.36), HMP ($r = 0.48$ *cf.* 0.25), fatigue index ($r = 0.71$ *cf.* 0.63),
41 $\%HR_{\text{peak}}$ ($r = -0.56$ *cf.* -0.35), RPE_{bout1} ($r = -0.44$ *cf.* -0.14), and RPE_{bout2} ($r = -0.68$ *cf.* -0.41)
42 than the Yo-Yo IR1, but not for blood lactate concentration ($r = -0.20$ to -0.28 *cf.* -0.35 to $-$
43 0.49). The relationships between prone Yo-Yo IR1 distance and measure of load during the
44 RLMSP-i suggests it possesses concurrent validity and is more strongly associated with
45 measures of training or match load than the Yo-Yo IR1 using rugby league players.

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

53 INTRODUCTION

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

61

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

71

72 Notwithstanding the multiple physiological contributors to performance during the Yo-Yo IR1
73 and 30-15 IFT, high-intensity intermittent running, as determined by the Yo-Yo IR1,
74 differentiates between playing standard, fatigue responses and match activity profiles in junior
75 male rugby league players (20). Those classified as high fitness covered greater distance, high-
76 speed running, number of collisions and number of repeated high-intensity efforts (20). Despite

77 this, Gabbett and Seibold (9) reported no significant relationship between Yo-Yo IR1 distance
78 and measures of match performance, including total ($r = 0.05$), low-speed ($r = 0.04$) and high-
79 speed ($r = 0.09$) distance as well as total collisions ($r = -0.70$) and repeated high-intensity
80 efforts ($r = -0.23$) in male semi-professional players. As intermittent running during rugby
81 match-play is frequently interspersed with collisions, which increases the physiological strain
82 imposed (25), it is likely that this action alters the relationship between an entirely running-
83 based intermittent field test and match-play as well as influencing the physiological
84 determinants being evaluated (2). As such, limitations with the concurrent validity of the Yo-
85 Yo IR1 and its association to rugby league match performance have been reported and suggest
86 a rugby-specific measure of HIIR is warranted (2).

87

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

99

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

109

110 **METHODS**

111 *Experimental Approach to the Problem*

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

122 *Subjects*

123 With institutional ethics approval, 36 Academy ($n = 20$) and University-standard ($n = 16$)
124 rugby league players (age 18.5 ± 1.8 years; stature 181.4 ± 7.6 cm; body mass 83.5 ± 9.8 kg)
125 completed the prone Yo-Yo IR1 and RLMSP-i, with a sub-sample (age 20.2 ± 1.1 years; stature
126 182.9 ± 6.7 cm; body mass 82.2 ± 8.3 kg) also completing the Yo-Yo IR1. All participants
127 provided written informed consent and completed a pre-test health questionnaire before
128 starting the study. Parental assent was provided for all participants < 18 years old. Participants
129 were free from injury at the start of the study, which was confirmed by the participants and the
130 club's medical team.

131 ***Procedures***

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

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

143 *Rugby League Movement Simulation for Interchange Players*

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

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

154 *External response*

155 Movement characteristics were recorded using a 10 Hz microtechnology device (Optimete S5,
156 Catapult Innovations, Melbourne, Australia) fitted into a custom-made vest positioned between
157 the participant’s scapulae. The mean \pm SD number of satellites and HDOP was 13.8 ± 1.1 and
158 0.7 ± 0.1 , respectively. Total distance was recorded and categorised into low ($< 14.0 \text{ km}\cdot\text{h}^{-1}$)
159 and high ($> 14.1 \text{ km}\cdot\text{h}^{-1}$) intensities (25). Mean speed was calculated and peak speeds ($\text{km}\cdot\text{h}^{-1}$)
160 of sprint A and B were measured; where sprint A and B represent the first and second 20.5
161 m sprint during each cycle of the simulation, respectively. Peak speed was determined as the
162 peak absolute speed reached during the whole simulation. The fatigue index was calculated
163 using all 48 sprint performances and the following equation: $Fatigue = 100 * EXP^{(slope/100)} - 100$,
164 where the slope is calculated using the line of best fit for: $100 \times \text{natural logarithm of sprint}$
165 $\text{data} \times (\text{number of sprint} - 1)$ (12). The built-in 100 Hz triaxial accelerometer, gyroscope and
166 magnetometer were used to determine high metabolic power (HMP) ($> 20 \text{ W}\cdot\text{kg}^{-1}$). In-house
167 analysis has revealed that the coefficient of variation for relative distance, low-speed running,
168 high-speed running and peak speed were between 1.3-1.9%, 2.2-3.3%, 8.0-14.4% and 3.7-
169 9.6%, respectively for bout 1 and 2 of the RLMSP-i (unpublished data).

170 *Internal and perceptual responses*

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

179

180 **Statistical Analyses**

181 Data are presented as mean \pm SD. To evaluate any changes between RLMSP-i bouts,
182 magnitude based-inferences were used with the following 90% confidence limits: < 0.5% most
183 unlikely, 0.5-5% very unlikely, 5-25% unlikely, 25-75% possibly, 75-95% likely, 95-99.5 very
184 likely, > 99.5 most likely. Magnitude of the observed change was assessed using the following
185 thresholds: trivial < 0.2, small 0.2 - 0.6, moderate 0.6 - 1.2, large 1.2 - 2.0, and very large > 2.0
186 (17). To assess associations between a range of internal and external measures and distance
187 covered during the prone Yo-Yo IR1, Pearson's correlation coefficient (r) with the following
188 criteria were adopted to interpret the magnitude of the correlation between variables: < 0.1,
189 *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-
190 1.0, *almost perfect* (16), and was based on the change between bouts for relative total, low-
191 speed and high-speed distance, mean speed and HMP, and raw values for fatigue index, the
192 percentage change between sprints A and B, $\%HR_{\text{peak}}$, RPE and $[La]_b$. If the confidence limits
193 overlapped small positive and negative values when comparing the between-bout responses

194 the effect was considered *unclear*. Statistical analysis was conducted using a predesigned
195 spreadsheet for comparing means (14) and assessing correlations (15).

196

197 **RESULTS**

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

205

Insert Table 1 Here

206

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

216

Insert Figure 1 Here

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

223 **Insert Figure 2 Here**

224 **Discussion**

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

233

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

240

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

253

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

262

263 We identified a *moderate* relationship between prone Yo-Yo IR1 distance and the change in
264 time spent at HMP ($> 20 \text{ W} \cdot \text{kg}^{-1}$) between bouts, suggesting those players who have greater

265 rugby-specific HIIR can sustain combined accelerated and high-speed running during the
266 RLMSP-i. In contrast, only a *small* relationship was observed between time spent at HMP and
267 total distance during the Yo-Yo IR1, suggesting the inclusion of a metabolically demanding
268 action during the prone Yo-Yo strengthens its relationship with simulated match-play. While
269 HMP underestimates the metabolic costs associated with the collision (13), this metric does
270 provide some evidence that rugby-specific HIIR is positively related to an individual's ability
271 to perform and sustain metabolically demanding actions during a simulated match. That is to
272 say, the prone Yo-Yo IR1 might provide further insight into a player's ability to maintain
273 fundamental movements across playing bouts, including accelerating, decelerating, changing
274 direction and getting up-and-down quickly.

275

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

289 emphasis on getting up and accelerating is more closely related to demands of repeated
290 sprinting during the RLMSP-i.

291

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

305

306 Despite similar movement demands, the reduction in external load between bouts (~5%) was
307 smaller than that observed during match-play (~15%) (29), which is likely due to the difficulties
308 in replicating the physical contact in the simulation (6,27). However, the use of simulated
309 match-play strongly suggests that prone Yo-Yo IR1 distance is related to commonly used
310 measures of load during activities that closely reflect match-play without interference from
311 match-related factors. Further research might explore the validity of the prone Yo-Yo IR1
312 against performance measures during match-play using a multilevel mixed model approach

313 that controls for other confounding variables and explores additional physical qualities. It is
314 also important to note that the correlations observed in this study are based on academy and
315 university-standard players who demonstrate a reduced prone Yo-Yo IR1 distance and lower
316 body mass compared to elite Super League players (unpublished data). As such, future research
317 might explore the relationship between prone Yo-Yo IR1 distance and measures of match
318 performance in elite players. Finally, whilst we have provided evidence that rugby-specific
319 HIIR is related to internal, external and perceptual measures of load, its influence on a player's
320 ability to maintain skill performance is unknown.

321

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

328

329 **PRACTICAL APPLICATIONS**

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

336 to minimise the anticipated reduction in intensity between bouts of activity in rugby league
337 match-play.

338

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

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