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Systematic reductions in differential ratings of perceived exertion across a 2-week repeated-sprint-training intervention that improved soccer players' high-speed-running abilities

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1 **Abstract**

2 *Purpose:* To quantify changes in differential ratings of perceived exertion  
3 (dRPE) across a two-week repeated-sprint training (RST) intervention that  
4 improved high-intensity intermittent running ability and linear speed of semi-  
5 professional soccer players.

6 *Methods:* Thirteen players completed 3 (sessions 1–3) or 4 (sessions 4–6) sets  
7 of 7 sprints (Group 1 [ $n = 7$  players]: 30-m straight; group 2 [ $n = 6$  players]:  
8  $2 \times 10$ -m shuttle), with 20 seconds and 4 minutes recovery between sprints  
9 and sets, respectively. Post-set perceptions of breathlessness (RPE-B) and leg  
10 muscle exertion (RPE-L) were rated using the CR100® scale.

11 *Results:* Overall, RPE-B (mean  $\pm$  SD:  $46 \pm 13$  arbitrary units [AU], ‘~hard’)  
12 was most likely higher than RPE-L ( $39 \pm 13$ , ‘~somewhat hard’. Mean  
13 difference: 8 AU; 90% confidence limits [CL]:  $\pm 2$ ). Set-to-set increases in  
14 dRPE (AU; 90% CL:  $\pm \sim 2$ ) were large in session 1 (RPE-B: 15, RPE-L: 14),  
15 moderate in sessions 2–5 (RPE-B: 7–10, RPE-L, 7–8), and small (RPE-B: 6)  
16 to moderate (RPE-L: 7) in session 6. Across the intervention, RPE-B reduced  
17 moderately in Set 3 ( $-13; \pm 4$ ) and 4 ( $-12; \pm 12$ ), and RPE-L reduced by a small  
18 magnitude in Set 3 ( $-5; \pm 6$ ). The Set 4 change in RPE-L was unclear ( $-11;$   
19  $\pm 13$ ).

20 *Conclusions:* We observed systematic intra- and inter-session changes in  
21 dRPE across a two-week RST intervention, with a fixed prescription of  
22 external load, that improved semi-professional soccer player’s high-speed  
23 running abilities. These findings could support dRPE as measures of internal  
24 load and highlight a usefulness in evaluating RST dose–response.

25 *Keywords:* RPE, sensitivity, athlete monitoring, training load, exercise  
26 progression.

27

28 **Introduction**

29 Quantifying the extent to which athletes are responding to a training session,  
30 intervention or programme is an integral part of monitoring and management  
31 strategies in sport.<sup>1,2</sup> Changes in training outcomes, such as aerobic capacity,  
32 strength, speed and power, are of very little value without precise, thorough,  
33 and in-depth information about the exercise training itself.<sup>3</sup> This includes both  
34 physical performance (i.e., external load) and the associated biochemical  
35 (physiological and psychological) and biomechanical responses (i.e., internal  
36 load).<sup>4,5</sup> The relationship between internal and external load can therefore  
37 provide insights to a player’s fitness or fatigue.<sup>6</sup> For example, a reduced  
38 internal load in response to a standardized external load may indicate a player  
39 is gaining fitness and coping with training.<sup>1</sup> This approach can be useful to  
40 evaluate training and prescribe subsequent activity, but is often limited due to  
41 difficulties in controlling external load under standardized conditions in the  
42 applied setting.<sup>1</sup>

43 Ratings of perceived exertion (RPE) are a commonly used measure of internal  
44 load in soccer.<sup>2</sup> This is likely due to strong associations with multiple  
45 indicators of internal exercise intensity, reliability, and feasibility.<sup>7</sup>  
46 Separating global RPE into its specific central and peripheral mediators (e.g.,  
47 respiratory and muscular, respectively) can further enhance internal load  
48 quantifications<sup>8</sup> and may well be a suitable indirect alternative measurement  
49 of physiological and biomechanical loads.<sup>5</sup> Differential RPE (dRPE)  
50 represent distinct psychophysiological constructs in team-sport athletes and  
51 have demonstrated face, content and construct validity (convergent and  
52 discriminant).<sup>8-10</sup> Despite a growing interest in dRPE as measures of internal  
53 load,<sup>11</sup> the dose–response sensitivity of perceived respiratory (central) and  
54 muscular (peripheral) exertion in relation to external loads and changes in  
55 fitness are largely unexplored.

56 Repeated-sprint training (RST) is a time-efficient, centrally and peripherally  
57 demanding exercise modality that is effective at improving speed, power, and  
58 high-intensity intermittent running performance in soccer players.<sup>12</sup> While  
59 repeated-sprint bouts ( $\geq 2$  sprints with  $< 60$  s recovery) seldom occur in  
60 match-play,<sup>13</sup> performing multiple, all-out efforts, over short distances with  
61 brief recovery periods can elicit cardiometabolic and neuromuscular  
62 adaptations favourable to soccer performance.<sup>13-15</sup> Evaluating dRPE in  
63 response to RST, where external load can be controlled, may therefore serve  
64 as an ideal exploratory examination of dose–response sensitivity.  
65 Accordingly, the objective of our study was to detail changes, if any, in dRPE  
66 across a controlled two-week RST intervention that substantially improved  
67 high-intensity intermittent running ability and linear speed in a group of semi-  
68 professional soccer players.<sup>16</sup>

69

## 70 **Methods**

### 71 *Participants*

72 Data from 13 semi-professional, male soccer players ([mean  $\pm$  SD] age: 24  $\pm$   
73 4 years; stature: 179  $\pm$  6 cm; body mass: 77  $\pm$  8 kg) who were part of a  
74 previously published randomised controlled trial<sup>16</sup> were used in our study. An  
75 initial sample of 15 players provided informed consent to participate in the  
76 RST intervention.<sup>16</sup> However, two players were excluded from the current  
77 analysis due to insufficient attendance (2–3 out of 6 training sessions). Players  
78 were part of two different squads, which competed in the eighth and ninth tier  
79 of the English Football League System. This study took part at the end of the  
80 competitive season and the RST interventions were included as total  
81 replacement of training.<sup>16</sup> No matches took place during this period. All  
82 players received medical clearance and provided informed consent to  
83 participate. The study received ethical approval via an institutional ethics  
84 committee.<sup>16</sup>

### 85 *Experimental Design*

86 The RST intervention was a quasi-experimental, controlled, pre–post parallel  
87 groups design in which players were allocated (via minimization) to either a  
88 straight-line (STR  $n = 7$ ) or change of direction (CoD;  $n = 6$ ) training group.  
89 Players from both squads had prior experience of RST as part of their usual  
90 training. However, this was the first instance in which a formal RST  
91 intervention was used as total replacement of training. A range of fitness tests  
92 assessing high-intensity intermittent running ability, speed, change of  
93 direction performance and lower-limb explosive power were conducted  
94 before and after the six-session programme.<sup>16</sup> Group mean fitness changes  
95 from the original sample of 15 players were moderate to large for the Yo-Yo  
96 Intermittent Recovery Test Level 1 (YYIRT1, 28%; 90% confidence limits  
97 [CL]:  $\pm 4$ ), and large for 5- (-9.5%;  $\pm 1.7$ ), 10- (-6.7%;  $\pm 1.2$ ), and 20-m (-3.8%;  
98  $\pm 0.8$ ) linear sprint times, with no clear difference between groups. No clear  
99 changes were observed in Illinois agility test performance (0.7%;  $\pm 1.4$ ) or  
100 countermovement jump height (1.6%;  $\pm 2.7$ ).

101 The six training sessions took place across a two-week period, which allowed  
102 for one session every 2–3 days. This time was chosen to ensure adequate  
103 recovery between sessions and to examine the proposed time-efficient nature  
104 of RST. Training sessions were performed outdoors on a grass soccer pitch at  
105 the same time of day for each team (19:00) to minimise any potential  
106 influence of diurnal or circadian variation on the internal response to exercise.  
107 We also asked players to avoid any additional vigorous exercise, mentally  
108 demanding tasks and foods or beverages containing stimulants (e.g., caffeine)  
109 in the 24-hours immediately prior to each training session, due to the putative  
110 effects on perceived exertion.

111 *Protocols*

112 All RST sessions were preceded with a 15-minute warm-up. The warm-up  
 113 consisted of: 5-minutes light jogging, 5-minutes lower-limb dynamic  
 114 stretching, and 5-minutes activation exercises (jumps, hops, skips, bounds),  
 115 and three sprint efforts (80%, 90% and 95% of perceived maximum speed).  
 116 The training programme consisted of 3 (Block 1: sessions 1–3) or 4 (Block 2:  
 117 sessions 4–6) sets of 7 sprints, with 20 seconds and 4 minutes recovery  
 118 between sprints and sets, respectively. The STR group completed 30-m  
 119 efforts and the CoD group completed  $2 \times 10$ -m efforts with a 180° turn. These  
 120 distances were chosen as per RST recommendations<sup>15</sup> and to ensure that  
 121 effort durations were closely matched between STR and CoD. For the purpose  
 122 of the present analysis, training data for STR and CoD were pooled so that  
 123 sample size was not compromised. Players were informed of the two-week  
 124 programme prior to the start of the intervention period and of sprint distances,  
 125 sets, repetitions, and rest periods prior to each session.

126 *Outcome Measures*

127 Throughout each session, beat-to-beat heart rate was measured by a chest-  
 128 worn belt (Polar T31 Coded, Polar Electro Oy, Finland), with data transmitted  
 129 to a wrist watch (Polar RS400, Polar Electro Oy, Finland) at a rate of 5 kHz.  
 130 Upon post-session download, raw data were aggregated into 5-second  
 131 intervals by the proprietary software (Polar ProTrainer 5, Polar Electro,  
 132 Kempele, Finland). Heart rate traces were then visually inspected and  
 133 sessions with clear irregularities (e.g., substantial trace dropout) were  
 134 removed from further analysis ( $n = 3$ ). Subsequently, set average heart rate  
 135 ( $HR_{avg}$ ) including between-sprint rest periods, was retained. Data was  
 136 expressed as a percentage of maximum heart rate, determined as the highest  
 137 value recorded during both YYIRTL1.

138 Player’s external training activities were monitored using microsensor units  
 139 containing a 10 Hz global positioning system (GPS) and a 100 Hz triaxial  
 140 accelerometer with an output range of  $\pm 13$  g. (MinimaxX v4.0, Catapult  
 141 Innovations™, Melbourne, Australia). Microsensor units were harnessed in a  
 142 tight-fit vest allowing for an anterior–posterior placement between the  
 143 scapulae. Players wore the same unit throughout the intervention period to  
 144 mitigate inter-unit error. Devices were activated 15-minutes prior to the start  
 145 of each training session to enable a suitable connection to the satellite  
 146 network. Data were retrospectively processed via proprietary software (Sprint  
 147 v5.1.7, Catapult Innovations), which smoothed raw velocity and  
 148 accelerometry data using bespoke algorithms (methods not publicly  
 149 available). Signal quality was visually inspected after each session and we  
 150 found no instances of inaccuracies.

151 Since the RST programme required players to run the same distance at the  
 152 same intensity for each sprint, traditional locomotor metrics (e.g., total and  
 153 high-speed running distances), were not considered as reflective external

154 measures. Instead, peak running speed ( $\text{km}\cdot\text{h}^{-1}$ ) and total PlayerLoad™ (PL,  
 155 arbitrary units [AU])<sup>17</sup> for each set of 7 sprints were extracted for analysis.  
 156 Ten hertz MinimaxX GPS have demonstrated good criterion validity (versus  
 157 laser: mean bias =  $\sim 3\%$ , coefficient of variation [CV] = 3–6%,  $r = 0.98$ ) and  
 158 high interunit reliability (CV = 4–6%,  $r = 0.89$ – $0.98$ ) for measuring  
 159 instantaneous velocity and peak speed during short, straight-line sprint and  
 160 shuttle efforts.<sup>18</sup> The inter- and intra-unit reliability of PL has been reported  
 161 as  $\sim 1\%$ .<sup>19</sup>

## 162 *Differential RPE*

163 One week prior to data collection, players were given instruction on the  
 164 definition of perceived exertion and its scaling,<sup>20</sup> including the importance of  
 165 separating RPE from other exercise related sensations such as pain,  
 166 discomfort and fatigue. Instruction was also given on how to appraise dRPE,  
 167 such that RPE-B depends mainly on breathing rate and/or heart effort, and  
 168 RPE-L depends mainly on the strain and exertion in the leg muscles (thighs,  
 169 glutes, calves, etc.). When players arrived for baseline fitness testing, above  
 170 instructions were verbally reiterated and any questions were answered  
 171 through discussion. This session was also used to familiarise players with data  
 172 collection, using post-warm-up and post-test periods to provide ratings across  
 173 different intensities of exercise (i.e. anchoring).

174 During RST, players used 7” Android tablets (Iconia One 7 B1-750, Taipei,  
 175 Taiwan: Acer Inc.) to independently record RPE-B and RPE-L via a  
 176 numerically blinded CR100® scale, hosted on a bespoke application.<sup>10</sup> Tablets  
 177 were circulated approximately one minute after each set of sprints. Players  
 178 were instructed that their ratings should reflect the perceptions of effort  
 179 experienced for the preceding set only (i.e. for the last seven sprints). Using  
 180 four tablets in rotation, dRPE were typically collected within a 2-minute post-  
 181 set period.

## 182 *Statistical Analysis*

183 Visual inspection of raw data via histograms and Q–Q plots showed  
 184 approximate normal distribution for dRPE,  $\text{HR}_{\text{avg}}$ , peak running speed and PL  
 185 in each set. Descriptive summary statistics are therefore presented as the mean  
 186  $\pm$  standard deviation (SD). Our design located units of analysis (outcome  
 187 measures for a set) nested in clusters of units (players). Since use of the  
 188 CR100® scale allows RPE to be treat as continuous ratio data, we used  
 189 separate 2-level linear mixed effect models (SPSS version 24, IBM, Armonk,  
 190 NY, US) to examine the changes in each outcome measure within a session  
 191 (set-to-set) and across the two-week intervention (between-sessions). Fixed  
 192 effects (modelled without a fixed intercept) were set and session number,  
 193 which were specified as continuous covariates (to determine the linearized  
 194 change between sets and across sessions) and factors (to determine these  
 195 changes on a per-session or per-set basis). Slope values for set were evaluated

196 as the change in each outcome measure associated with performing one set of  
197 seven sprints. Session was rescaled when entered as a covariate (ranging from  
198 0 to 1) so that slope values represented the linearized change in outcome  
199 measures across the entire two-week programme (i.e. the effects of 6  
200 sessions). Models were fit with a random intercept for athlete and a random  
201 slope for set or session, using an unstructured covariance matrix, to account  
202 for individual differences in the linearized changes.

203 Uncertainty in outcome measures and ranges of values compatible with our  
204 data and statistical models were expressed as 90% CL.<sup>21</sup> We then used non-  
205 clinical magnitude-based decisions<sup>22,23</sup> to provide an interpretation of these  
206 ranges in relation to reference thresholds. In the absence of a robust anchor  
207 for practically meaningful changes in all our outcome measures, we elected  
208 to use a distribution-based approach (i.e. standardization) to determine these  
209 thresholds.<sup>24</sup> Standard deviations for the intercept (between-athlete) and  
210 residual were pooled and multiplied by thresholds of 0.2, 0.6, 1.2, and 2.0  
211 anchor small, moderate, large, and very large changes, respectively.<sup>23</sup>  
212 Subsequently, the chance of a change being substantial or trivial was  
213 calculated by converting the *t* statistic for the effect in relation to the threshold  
214 (change – threshold/ standard error of the change) to a continuous probability  
215 via the one-tailed *t*-distribution.<sup>25</sup> Quantitative probabilities were then  
216 assigned to the following qualitative probabilistic terms: possibly, 25.0–  
217 74.9%; likely, 75.0–94.9%; very likely, 95.0–99.5%; most likely > 99.5%.<sup>22</sup>  
218 The effect was declared unclear if the chance of being both substantially  
219 positive and negative was  $\geq 5\%$ . Each effect and its CL were converted to  
220 standardized units (effect sizes) for visualisation.  
221



222 **Results**

223 Descriptive data for each set of repeated sprints across the 6-session RST  
224 intervention are presented in Figure 1 and Figure 2. The overall (mean  $\pm$  SD)  
225 set values were  $46 \pm 13$  AU (‘hard’) for RPE-B,  $39 \pm 13$  AU (‘somewhat  
226 hard’) for RPE-L,  $80 \pm 6\%$  for HR<sub>avg</sub>,  $24.1 \pm 4.4$  km·h<sup>-1</sup> for peak running  
227 speed and  $31 \pm 5$  AU for PL. Mean RPE-B was most likely higher than RPE-  
228 L (mean difference: 8 AU; 90% CL:  $\pm 2$ ). Differential RPE were likely higher  
229 for the STR training group (RPE-B:  $50 \pm 16$ , RPE-L:  $43 \pm 16$ ) when compared  
230 with the CoD training group ( $42 \pm 15$ ,  $35 \pm 13$ . Mean difference: 7 AU; 90%  
231 CL:  $\pm 9$ ).

232 **\*\*INSERT FIGURE 1 NEAR HERE\*\***

233 **\*\*INSERT FIGURE 2 NEAR HERE\*\***

234 The change in dRPE, HR<sub>avg</sub>, peak running speed, and PL per one set of  
235 repeated sprints are presented in Figure 3. Set-to-set changes in RPE-B (AU;  
236 90% CL:  $\pm \sim 2$ ) were large in session 1 (15 AU), moderate in sessions 2–5 (7–  
237 10 AU), and small in session 6 (6 AU). For RPE-L, set-to-set changes ( $\pm \sim 2$   
238 AU) were large in session 1 (14 AU) and moderate in sessions 2–6 (7–8 AU).  
239 Set-to-set changes in HR<sub>avg</sub> were small in sessions 1, 3, and 5 ( $\sim 1.3\%$ ;  $\pm \sim 1.0$ ).  
240 No substantial set-to-set changes were observed in any other sessions for  
241 HR<sub>avg</sub> ( $\sim 0.9\%$ ;  $\pm \sim 1.0$ ) or in any of the 6 session for peak running speed ( $\sim 0.1$   
242 km·h<sup>-1</sup>;  $\pm \sim 0.3$ ) and PL ( $\sim 0.04$  AU;  $\pm \sim 0.58$ ).

243 **\*\*INSERT FIGURE 3 NEAR HERE\*\***

244 Changes in dRPE, HR<sub>avg</sub>, peak running speed, and PL across the RST  
245 intervention are presented in Figure 4. Breathlessness RPE increased by a  
246 small magnitude in Set 1 (6 AU;  $\pm 5$ ) and reduced by a moderate magnitude  
247 in Sets 3 (-13 AU;  $\pm 5$ ) and 4 (-12 AU;  $\pm 14$ ). The Set 2 change in RPE-B was  
248 unclear (2 AU;  $\pm 5$ ). Leg muscle RPE increased by a small magnitude in Set  
249 1 (5 AU;  $\pm 5$ ) and 2 (6 AU;  $\pm 5$ ), and reduced by a small magnitude in Set 3 (-  
250 5 AU;  $\pm 5$ ). The Set 4 change in RPE-L was unclear (-11 AU;  $\pm 14$ ). Changes  
251 in other measures of intensity and load were as follows: PL reduced by a  
252 moderate magnitude in Set 4 (-3.5 AU;  $\pm 3.4$ ); HR<sub>avg</sub> and peak running speed  
253 reduced by a small magnitude in Sets 2 (-1.3%;  $\pm 0.4$ ) and 4 (-1.1 km·h<sup>-1</sup>;  
254  $\pm 1.4$ ), respectively, and; no substantial changes were observed in peak  
255 running speed for sets 1 to 3 (-0.1 km·h<sup>-1</sup>;  $\pm 0.6$ ), or in PL during set 3 (-0.9  
256 AU;  $\pm 1.4$ ). All other between-session changes were unclear.

257 **\*\*INSERT FIGURE 4 NEAR HERE\*\***

258

259 **Discussion**

260 There is limited data examining the dose–response relations of dRPE with  
261 external load and fitness in team sports. In this exploratory study, we  
262 quantified changes in dRPE throughout a 6-session RST intervention with a  
263 fixed prescription of external load that improved high-intensity intermittent  
264 running ability and linear speed in semi-professional soccer players.<sup>16</sup> Our  
265 main finding was the systematic intra- and inter-session changes in RPE-B  
266 and RPE-L across the intervention period. Ratings for final sets of sprints  
267 reduced across the intervention and within-session changes became less  
268 substantial towards the end of the training programme. These findings suggest  
269 dRPE to be sensitive to changes in high-intensity running abilities. Our data  
270 therefore support dRPE as measures of internal load and highlight a  
271 usefulness in evaluating training dose–response during repeated-sprint  
272 protocols.

273 Players in our investigation perceived RST as ‘somewhat hard’ to ‘hard’, with  
274 RPE-B being most likely higher than RPE-L. These data are in contrast to the  
275 expected responses of RST, however, which are usually described as more  
276 peripherally demanding and perceived ‘hard’ to ‘very hard’.<sup>14,15</sup> Nonetheless,  
277 RST is programmed with disproportionate inter- and intra-set recovery  
278 periods so that internal load cumulates with each successive bout.<sup>26</sup> Our data  
279 suggest that such an outcome was achieved, as RPE-B and RPE-L increased  
280 substantially across successive sets of sprints. These changes might be  
281 explained by metabolic and neuromuscular consequences,<sup>26</sup> inclusive of  
282 anaerobic energy contribution, glycogen depletion and insufficient  
283 phosphocreatine resynthesis, hydrogen ion accumulation, respiratory  
284 compensations, and reductions in muscle excitability and excitation-  
285 contraction coupling.<sup>15</sup> A substantially higher RPE-B in comparison to RPE-  
286 L has also been reported for other forms of ‘short’ high-intensity interval  
287 training (HIT). McEwan and colleagues<sup>27</sup> found comparable differences  
288 between dRPE (mean RPE-B: 80–85 AU, mean RPE-L: 71–75 AU)  
289 following 12 × 30 s treadmill running intervals at 105% maximum aerobic  
290 speed with both externally regulated (30 s) and self-selected recovery periods.  
291 Participants who cited the completion of HIT sessions as their objective were  
292 also found to have utilised heart and respiration rate when gauging their  
293 perceived readiness to commence the next interval.<sup>27</sup>

294 A novel finding from our data was the reduced magnitude of set-to-set  
295 changes in dRPE across the 6 training sessions, despite no meaningful  
296 changes in external load or intensity (Figure 3). A further key finding was the  
297 small to moderate reduction in dRPE following the third set of sprints (Figure  
298 4). This again occurred despite trivial changes in external load/ intensity  
299 throughout the two-week intervention (Figure 4). Since moderate to large  
300 improvements in YYIRTL1 and linear speed were evident following  
301 completion of the RST intervention,<sup>16</sup> it is possible that these systematic  
302 reductions are, in part, due to training-induced cardiometabolic and  
303 neuromuscular adaptations. Such a finding could be supportive of a dose–  
304 response relationship between dRPE and the factors underpinning high-speed

305 running abilities.<sup>1,4,6</sup> The beneficial effects of RST likely occur in the early  
306 part of a programme (e.g. as little as 6 sessions),<sup>16</sup> and may be a consequence  
307 of increased resting glycogen and phosphocreatine stores, muscle enzymatic  
308 activity and buffering capacity, muscle-fibre type and recruitment, and motor-  
309 unit synchronization and firing frequency.<sup>13-15</sup>

310 Contemporary psychophysiological theory suggests that effort perception is  
311 generated via corollary discharge of central motor commands.<sup>28</sup> It could  
312 therefore be speculated that cardiometabolic and neuromuscular adaptations  
313 to RST likely influence dRPE through reductions in the magnitude of central  
314 motor command to the respiratory and skeletal (leg) muscles. Although this  
315 efference model suggests that afferent feedback from inputs to the central  
316 nervous system—such as pulmonary vagal afferents and skeletal muscle  
317 tissue—are not the sensory signal generating perception of effort,<sup>28</sup> fatigue-  
318 induced spinal or supraspinal motoneuron inhibition can increase central  
319 motor command to maintain performance output during exercise,<sup>20</sup> thereby  
320 creating an indirect link between afferent feedback and RPE. Though we did  
321 not directly measure training ‘performance’ (repetition sprint time), very  
322 large to near-perfect within-player associations between PL and sprint  
323 decrement have previously been reported during CoDRST ( $r = 0.84-0.99$ ).<sup>17</sup>  
324 This suggests that accelerometer load may be a useful surrogate indicator of  
325 neuromuscular fatigue during RST. This application is based on the theory  
326 that reductions in the force-generating capacity of the lower-limb muscles  
327 increases ground contact time and centre of mass displacement during the  
328 stance phase of gait,<sup>29</sup> which adds further support to our observed data and  
329 conclusions. A limitation of this approach, however, is that the proportion of  
330 PL occurring in the straight line phase versus the turn is unknown.<sup>17</sup>

331 Initial-set dRPE increased by a small magnitude over the 6-session  
332 intervention. This could imply regression to the mean as an explanation for  
333 changed, rather than any training-induced adaptations. It is also difficult to  
334 draw conclusions from between-session changes in dRPE following the  
335 fourth set of sprints (performed only in sessions 4, 5 and 6), since there were  
336 possibly small to moderate reductions in external load/intensity. Finally, the  
337 observed changes in dRPE may have occurred, at least in part, due to  
338 psychological mechanisms, such as further familiarisation with RPE scaling  
339 (i.e., anchoring effects),<sup>30</sup> changes in teloanticipation or the RPE template,<sup>31</sup>  
340 or more positive task affect and self-efficacy towards the end of the  
341 intervention.<sup>32</sup> Nonetheless, we found the set-to-set changes in set HR<sub>avg</sub> to  
342 be inconsistently trivial and small. When coupled with the unclear between-  
343 session changes in latter set HR<sub>avg</sub>, this might further question the usefulness  
344 of heart rate monitoring (when expressed as an exercise average) for  
345 evaluating the response to maximal-effort forms of HIT.<sup>14</sup>

346 A limitation of our study is the pooling of both RST training groups in the  
347 analysis of training data, despite no clear between-group differences in fitness  
348 changes.<sup>16</sup> Subgroup analysis or the addition of group as a moderating factor  
349 was precluded due to the low sample of players. This is also the reason we  
350 did not perform any direct inferential comparison of the changes between

351 RPE-B and RPE-L, despite this being of a clear interest to the application of  
352 dRPE in training monitoring. A larger sample size in future investigations  
353 may allow for further comparisons of interest to be made. Furthermore, we  
354 did not objectively measure environmental conditions (e.g., wind, heat,  
355 ground stiffness), which may affect the perception of effort. It is also  
356 important to acknowledge that we implemented RST as a total replacement  
357 for normal training. This allowed for a more controlled assessment of the  
358 dRPE responses to a fixed external loads and systematic fitness changes, but  
359 represents a less ecologically valid situation in the holistic team-sport training  
360 schedule. Finally, we attempted to quantify the external load of each training  
361 session through peak speed and PL. While our RTS sessions were  
362 standardized, these measures may not necessarily capture the entire  
363 performance demands of sprint-type training in comparison with other, more  
364 complex outcomes (e.g., force–velocity profiling).

365 **Practical implications**

366 The collection of within-session dRPE and subsequent post-session analysis  
367 of data might offer a time-efficient means of determining if RST has been  
368 implemented as intended, in a comparable manner to all athletes (i.e.,  
369 fidelity), and if they are *generally* gaining fitness or responding to training.  
370 This pragmatic approach can be beneficial in team-sports such as soccer,  
371 given the congested fixture schedule and allocation of time to technical–  
372 tactical preparation, which limits frequent use of formal ‘fitness’ tests. Our  
373 findings and methodology may also be useful for on-field monitoring of  
374 individuals or small groups undertaking RST. For example, ‘top-up’ sessions  
375 for substitute players or those not selected for the weekly competitive fixture,  
376 as well as injured players during late-stage return-to-play/train strategies. In  
377 both these scenarios, the low number of players lends to on-field collection  
378 of dRPE and heuristic decision making, if the usual responses to previous  
379 RST sessions are known. For example, this information could be used to  
380 regulate training session volume (number of reps or sets) or recovery  
381 duration.

382 **Conclusions**

383 Monitoring the responses to training interventions can help identify training-  
384 induced adaptations and be useful for athlete management. A reduction of  
385 internal load to a standardized external load may indicate that an athlete is  
386 gaining fitness. In our current investigation, RPE-B and RPE-L  
387 systematically reduced across a two-week RST intervention that improved  
388 high-intensity running abilities of semi-professional soccer players, despite  
389 limited changes in external training load. Such a finding provides evidence to  
390 suggest that RPE-B and RPE-L may be useful to evaluate dose–response  
391 during RST.

392

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493 **Figure Captions**

494 *Figure 1:* Descriptive data (mean  $\pm$  standard deviation) for ratings of  
 495 perceived breathlessness (RPE-B) and ratings of perceived leg muscle  
 496 exertion (RPE-L) throughout the 6-session repeated-sprint training  
 497 intervention.

498 *Figure 2:* Descriptive data (mean  $\pm$  standard deviation) for average heart rate  
 499 ( $HR_{avg}$ ), PlayerLoad™ (PL), and peak running speed throughout the 6-session  
 500 repeated-sprint training intervention.

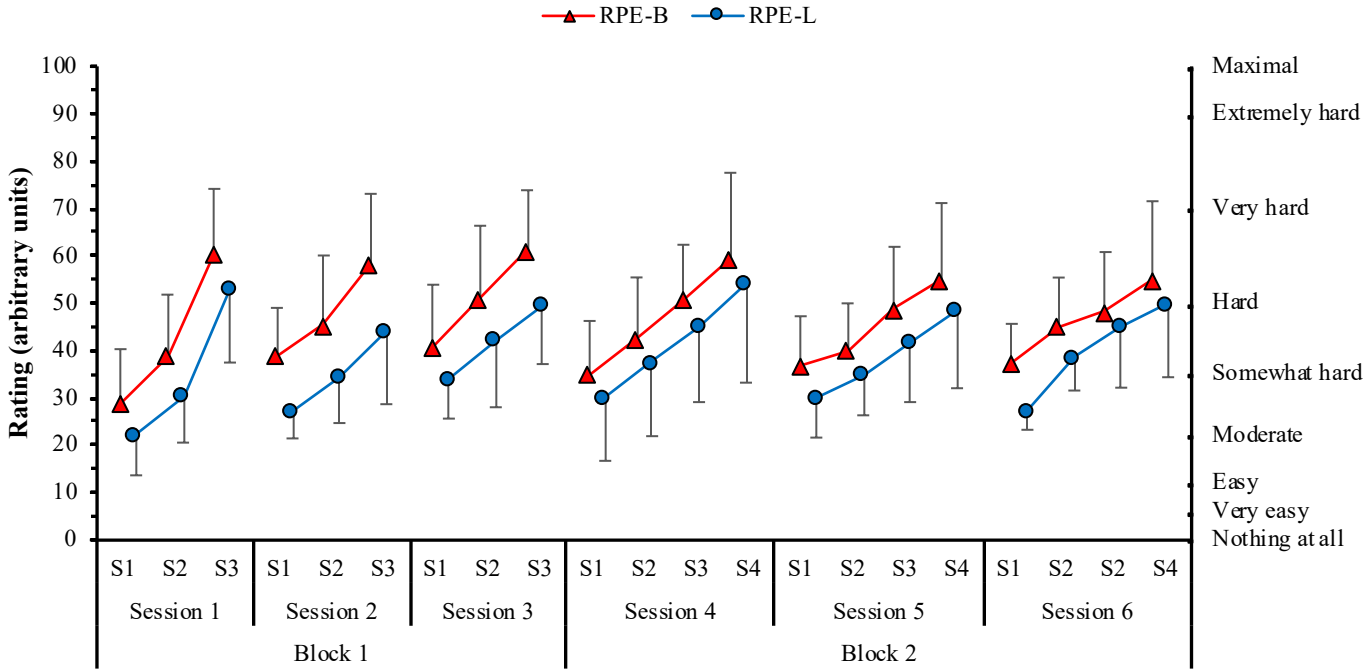
501 *Figure 3:* Set-to-set changes in ratings of perceived breathlessness (RPE-B),  
 502 ratings of perceived leg muscle exertion (RPE-L), average heart rate ( $HR_{avg}$ ),  
 503 PlayerLoad™ (PL), and peak running speed throughout the 6-session  
 504 repeated-sprint training intervention. Data are presented as effect sizes with  
 505 90% confidence limits.

506 [Footnote] Grey shaded area = trivial. Possibly trivial and small effects  
 507 are presented with the corresponding probabilities (percentage chance)  
 508 of being trivial (T) and small (S). All other effects are presented with  
 509 the percent chance of being the observed magnitude (moderate: M,  
 510 large: L), noted as: \*possibly (25.0–74.9%), \*\*likely (75.0–94.9%),  
 511 \*\*\*very likely (95.0–99.5%), and the probability of being trivial, noted  
 512 as:  $\alpha$ most unlikely ( $\leq 0.5\%$ ),  $\beta$ very unlikely (5.0–4.9%). Data points  
 513 without labels were likely to most likely trivial (90.0–99.9%)

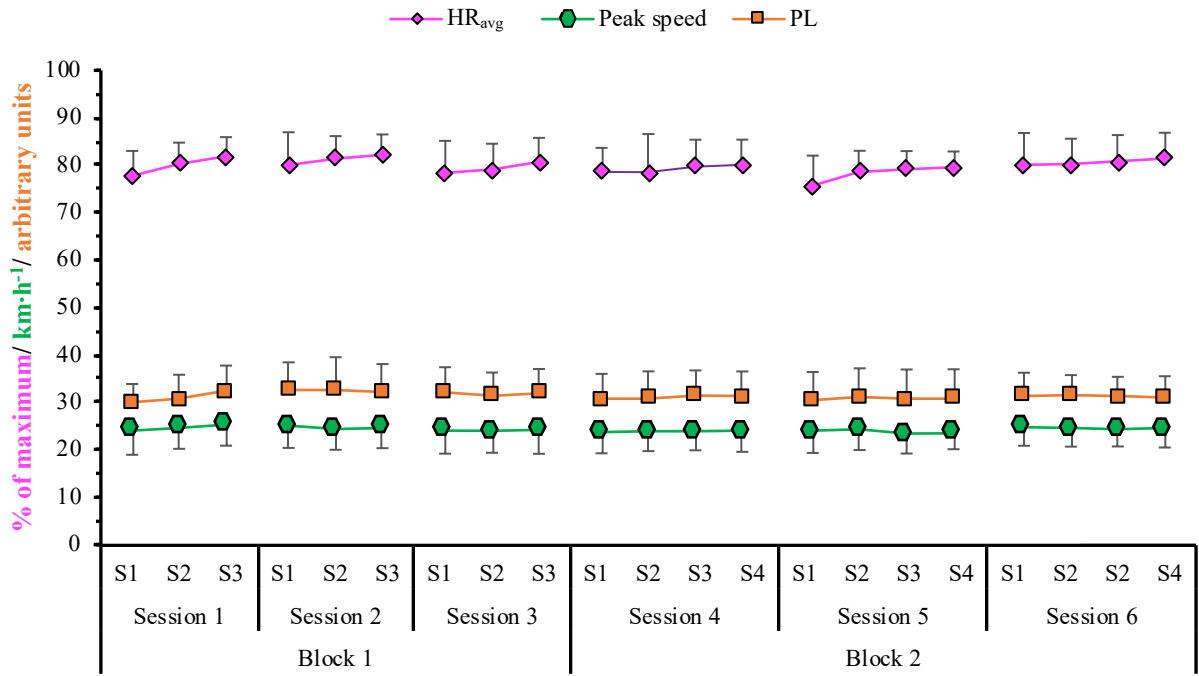
514 *Figure 4:* Changes in ratings of perceived breathlessness (RPE-B), ratings of  
 515 perceived leg muscle exertion (RPE-L), average heart rate ( $HR_{avg}$ ),  
 516 PlayerLoad™ (PL), and peak running speed across the 6-session repeated-  
 517 sprint training intervention. Data are presented as effect sizes with 90%  
 518 confidence limits.

519 [Footnote] Grey shaded area = trivial. Unclear, trivial and small effects  
 520 are presented with the probabilities (percentage chance) of being a  
 521 substantial  $\downarrow$ / trivial/ substantial  $\uparrow$ . All other effects are presented with  
 522 the percent chance of being the observed magnitude. For likely  
 523 substantial effects, the probability of being trivial is noted as:  $\alpha$ most  
 524 unlikely ( $< 0.5\%$ ),  $\beta$ unlikely (5.0–24.9%).

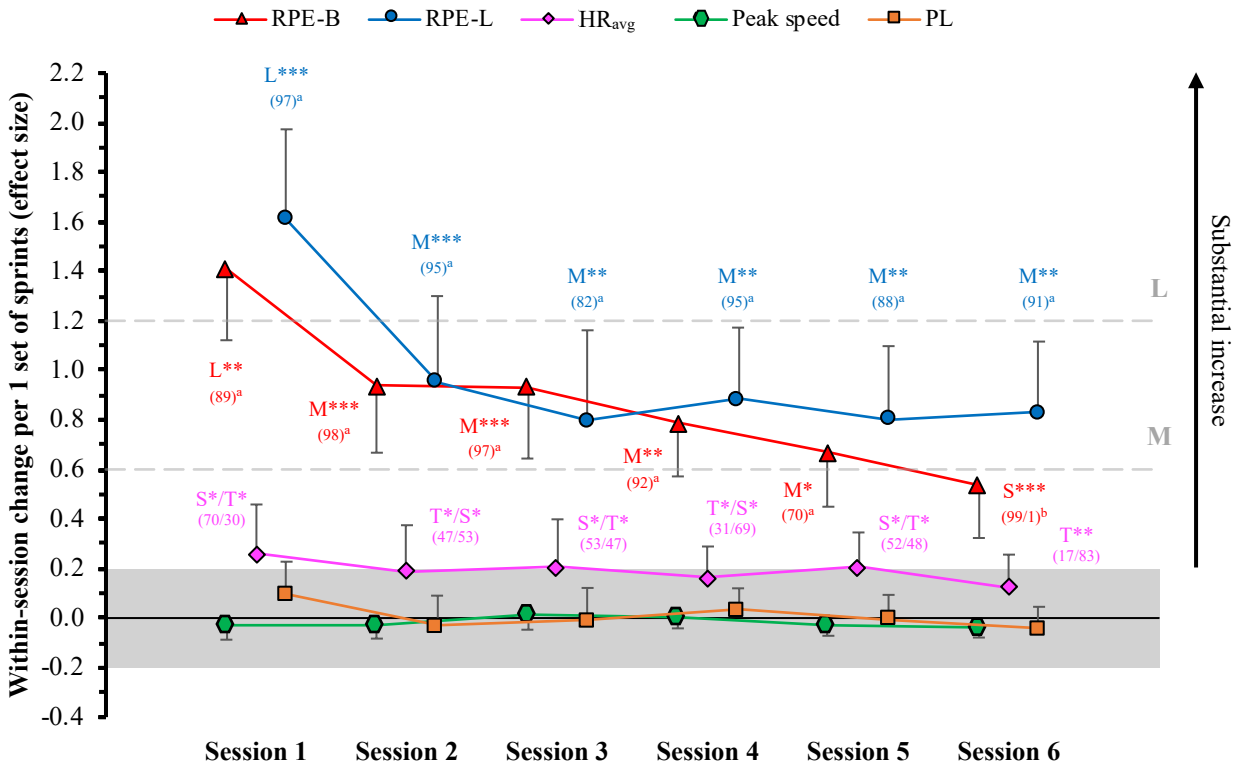
**FIGURE 1**



**FIGURE 2**



**FIGURE 3**



**FIGURE 4**

