

1 **Manuscript full title:** Biomechanical and physiological responses to 120 minutes of soccer-specific
2 exercise.

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23

24 **Abstract**

25 **Purpose:** To investigate biomechanical and physiological responses to soccer-specific exercise
26 incorporating an extra time period (ET) and assess the test-retest reliability of these responses.

27 **Methods:** Twelve soccer players performed 120 min of soccer-specific exercise. Tri-axial (PL_{Total}) and
28 uni-axial PlayerLoad™ in the vertical (PL_V), anterior-posterior (PL_{A-P}) and medial-lateral (PL_{M-L})
29 planes **were** monitored using a portable accelerometer. Likewise, respiratory exchange ratio (RER) was
30 recorded throughout exercise. At the end of each 15 min period, players provided differential ratings of
31 perceived exertion ([d-RPE]) for legs [RPE-L], breathlessness [RPE-B] and overall [RPE-O]) and
32 capillary samples were taken to measure blood lactate (BLa) concentrations. The soccer-specific
33 exercise was completed twice within seven days to assess reliability. **Results:** A main effect for time
34 was identified for PL_{Total} ($p = 0.045$), PL_V ($p = 0.002$), PL_{A-P} ($p = 0.011$), RER ($p = 0.001$), RPE-L ($p =$
35 0.001), RPE-O ($p = 0.003$) and CMJ ($p = 0.020$). A significant increase in PL_{Total} (234 ± 34 a.u) and
36 decrease in RER (0.87 ± 0.03) was evident during 105-120 min versus 0-15 min (215 ± 25 a.u; $p =$
37 0.002 and 0.92 ± 0.02 ; $p = 0.001$). Coefficient of variations were <10% and Pearson's correlation
38 coefficient demonstrated moderate to very strong (0.33-0.99) reliability for all PL variables, RPE-B,
39 BLa and RER. **Conclusions:** These results suggest that mechanical efficiency is compromised and an
40 increased rate of lipolysis is observed as a function of exercise duration, particularly during ET. This
41 data has implications for practitioners interested in fatigue-induced changes during ET.

42 **Keywords** Football, PlayerLoad™; Oxygen consumption; Perceived exertion; Fatigue; Reliability

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49 **Introduction:**

50 Professional soccer players are reported to cover a total distance of 9-12 km during a typical 90 min
51 match (Mohr, Krstrup, & Bangsbo 2003). This activity involves frequent changes of direction,
52 periods of high-speed running (HS) and sprinting, as well as rapid accelerations and decelerations that
53 may result in temporary fatigue (Stølen, Chamari, Castagna & Wisløff, 2005). This is evidenced by
54 reductions in HS distances during the second half compared to the first half in Premier League
55 matches, both with (Bradley et al., 2009) and without the ball (Di Salvo, Gregson, Atkinson, Tordoff
56 & Drust, 2009). In recent years, researchers have investigated these responses during 120 min of
57 soccer-specific exercise (i.e., with the addition of a 30 min extra-time [ET] period). This period of
58 match-play is required in domestic and international tournaments when matches are tied at the end of
59 90 min. Notably, at the previous four FIFA World Cups, 36% of knockout phase matches have
60 proceeded to ET with 50% at the 2014 tournament requiring 120 min of match-play (Harper,
61 Fothergill, West, Stevenson & Russell, 2016a).

62

63 To date, observations across 120 min of soccer match-play demonstrate that distances covered, and
64 the number of accelerations, decelerations and number of HS sprint efforts performed are reduced in
65 professional players during ET versus 90 min (Russell, Sparkes, Northeast & Kilduff, 2015; Winder,
66 Russell, Naughton & Harper, 2018). Moreover, a reduction in the number of dribbling and passing
67 actions in elite soccer players has been reported during the final 15 min of ET compared with a
68 number of other time points during matches (Harper, West, Stevenson & Russell, 2014). However, it
69 is unlikely that decreases in the number of actions are explained by a reduction in skill proficiency,
70 rather, a fatigue-related compromised ability to be involved with build-up play. In further support of
71 this notion, increased neuromuscular fatigue (i.e., reduced muscle force production) has been
72 observed during and following ET (Goodall et al., 2017). Furthermore, higher plasma glycerol, non-
73 esterified fatty acids (NEFA) and adrenaline as well as lower blood lactate (BLa) and glucose has
74 been observed during ET, which is indicative of an increase rate of lipolysis (Stevenson et al., 2017).
75 This change in energy pathway potentially explains the reductions in HS and sprint performance

76 (Russell et al., 2015; Harper et al., 2016b) as evidence suggests that the favourable energy pathway to
77 fuel high-intensity exercise is glycogenolysis (Mohr et al., 2005). These changes are notable as ET is
78 typically played in important cup and tournaments, and indeed, matches often progress to or are
79 decided during this period.

80

81 Researchers have previously measured responses to 90 and 120 min of soccer using both match-play
82 and simulations (Page, Marrin, Brogden & Greig, 2015; Russell et al., 2015; Harper et al., 2016b).
83 Whilst match-play provides high ecological validity, between match physical performance is highly
84 variable (Carling, Bradley, McCall & Dupont, 2016) and logistical constraints limit physiological
85 measurements during competitive games (Coutts et al., 2009). Therefore, simulating soccer match-
86 play has been proposed as a feasible alternative which further reduces injury-risk by negating the
87 physical contact associated with match-play (Page et al., 2015), which is responsible for ~70% of
88 injuries (Aoki, O'Hata, Kohno, Morikawa & Seki, 2012). However to date, the Soccer Match
89 Simulation (Russell, Rees, Benton & Kingsley, 2011) is the only reliable soccer-exercise stimulus
90 over 120 min (Harper et al., 2016b). This free-running soccer-specific exercise incorporates skill
91 actions and changes of direction, although due to pacing, potentially fails to elicit a mechanistically
92 valid fatigue-response inherent within treadmill-based protocols (Page, Marrin, Brogden & Greig,
93 2019). Furthermore, treadmill simulations eliminate self-pacing as periods of workload are
94 standardised and thus, changes in a given variable are likely fatigue-induced (Page et al., 2015). A
95 validated motorised treadmill simulation has been used previously to investigate changes in
96 physiological and biomechanical responses across 90 min of soccer-specific exercise (Page et al.,
97 2015). This simulation has also shown to be valid over 120 min as distances covered (Winder et al.,
98 2018) and number of sprints actions (Russell et al., 2015) are consistent with 120 min of actual-match
99 play. However, the test-retest reliability has not previously been assessed and thus there is scope to
100 further investigate reliability of these responses over 120 min.

101

102 Over recent years, assessments of within-match fatigue profiles have become increasingly common
103 since International Football Association Board (IFAB) approved the use of wearable technologies

104 (e.g., accelerometers). A novel metric that has been proposed by Catapult Innovations as a measure of
105 movement efficiency is that of PlayerLoad™ (PL) (Cormack, Mooney, Morgan & McGuigan, 2013).
106 This parameter is defined as the instantaneous rate of acceleration across three planes of motion (i.e.,
107 vertical, anterior/posterior and medial/lateral) and otherwise referred to as ‘jerk’ (Nicolella, Torres-
108 Ronda, Saylor & Schelling, 2018). Previously, changes in PL have been observed during the latter
109 stages of a contemporary 90 min soccer simulation, indicating a fatigue-induced deterioration in
110 movement efficiency (Page et al., 2015). These fatigue patterns are analogous with those of a match
111 (Bradley et al., 2009) which can manifest through a reduced vertical stiffness in the lower extremities
112 (detectable *via* changes in PL/jerk) (Oliver, Croix, Lloyd & Williams, 2014). The aetiology of such
113 changes may be a decreased neuromuscular control (Oliver et al., 2014), potentially compromising
114 dynamic joint stability (Hughes & Watkins, 2008). This could be owing to a reduced absorption
115 capacity and increased stress response to soft tissues (Hughes & Watkins, 2008), leading to impaired
116 movement efficiency which suggests an increased load per distance covered (Barrett et al., 2016) and
117 potential increased injury-risk. Furthermore, recent research suggests that exacerbated recovery
118 following matches that proceed to ET (Winder et al., 2018) may potentially predispose players to
119 injury, especially during fixture congested microcycles (Silva et al., 2018). Possible risk factors for
120 injury may involve lower limb muscle activity reductions and inhibited recovery kinetics, contributing
121 to subsequent impeded movement quality whilst performing explosive and unaccustomed activities
122 (Silva et al., 2018). Therefore, investigating changes in PL responses over 120 min may help elucidate
123 whether recovery and injury-risk are impacted further by the additional duration and workload
124 associated with ET.

125

126 Whilst PL is a useful measure of external load, internal load (e.g., heart rate [HR] and rating of perceived
127 exertion [RPE]) can provide important information pertaining to the impact of external stressors
128 (Macpherson et al., 2019). Whilst increases in RPE have been observed during ET (Harper et al.,
129 2016b), differential RPE (d-RPE) responses have yet to be collected during this period. This method
130 comprises three discrete scores for breathlessness (RPE-B), legs (RPE-L) and overall (RPE-O) loads

131 (Borg et al., 2010). It has previously been employed as an approach to measuring exertional perceptions
132 in soccer training (Macpherson et al., 2019) and 15-30 min post soccer match-play (Barrett, McLaren,
133 Spears, Ward, & Weston, 2018). Given the demands of soccer are multifactorial, d-RPE may highlight
134 distinct mechanisms of fatigue (Macpherson et al., 2019). For instance, RPE-L could quantify
135 peripheral and mechanical loads which in turn inform the need for strength, power or endurance work
136 on specific working muscles (Weston et al., 2015). Whereas consistent high RPE-B could indicate a
137 higher central and physiological load imposed on players, highlighting the need for aerobic training.
138 Furthermore, as this measure is applied, sensitive and easily administered (Macpherson et al., 2019),
139 investigating d-RPE responses may assist in capturing multiple dimensions of exertion to facilitate
140 understanding of players perceptions of load over 120 min of soccer-specific exercise.

141

142 As mentioned previously, ET may cause a change in the predominant energy source used (i.e.,
143 endogenous carbohydrate [CHO] to fat) (Stevenson et al., 2017). However, previous researchers have
144 used venous blood samples to estimate these changes in substrate utilisation over 120 min (Stevenson
145 et al., 2017), which is logistically difficult to measure during exercise. An alternative measure used to
146 estimate relative proportions of CHO and fat oxidation is the respiratory exchange ratio (RER). This
147 measure calculates volumes of gas exchange (i.e., O₂ uptake and CO₂ production) through use of a breath-
148 by-breath system (Goedecke et al., 2000). Indeed, treadmill-based simulations offer a feasible approach
149 to measuring RER as fixed periods of exercise intensity are required (Page et al., 2015). Likewise, using
150 treadmills to apply fixed workloads is essential to assess changes in substrate throughout exercise when
151 using the Wasserman et al. (1987) equation to calculate RER. To date, researchers have yet to employ
152 treadmill-based soccer simulations for ET and have thus far failed to calculate RER over 120 min.
153 Therefore, using RER to estimate substrate utilisation may provide practitioners and coaches with novel
154 insight into CHO usage during ET and whether CHO intake must be modulated to spare endogenous
155 CHO use and help maintain performance.

156

157 To the authors' knowledge, no study has aimed to quantify biomechanical (i.e., PL) responses and
158 measure substrate utilisation (through RER) or collect d-RPE over 120 min of soccer-specific exercise.
159 Therefore, this study aimed to investigate the biomechanical and physiological responses to 120 min of
160 treadmill-based soccer-specific exercise. A secondary aim was to examine the test-retest reliability of
161 these responses. We hypothesised that changes in PL would be indicative of a reduced efficiency and
162 that a shift in RER values towards predominant use of fat oxidation would be observed during ET. In
163 addition, it was postulated that d-RPE would increase as a function of exercise duration.

164

165 **Materials and methods**

166 *Participants and experimental authorisation*

167 University-standard (n=6) and semi-professional (n=6) outfield soccer players (age: 21.3 ± 2.9 years,
168 stature: 178.5 ± 7.1 cm, mass: 70.42 ± 8.47 kg, maximal oxygen uptake [$\dot{V}O_{2\max}$]: 56.58 ± 7.23
169 $\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$, max heart rate (HR): 199 ± 3 $\text{b}\cdot\text{min}^{-1}$) with two or more years of soccer experience were
170 recruited for participation. Exclusion criteria specified the diagnosis of lower-limb musculoskeletal
171 injury within the preceding six months, any medical condition affecting participation following
172 completion of a medical screening questionnaire and a $\dot{V}O_{2\max} \leq 48.5$ $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, consistent with
173 previous ET literature (Stevenson et al., 2017). Furthermore, participants were asked to refrain from
174 strenuous exercise 48 h prior to testing. Institutional ethical approval was granted to allow the
175 undertaking of research and written informed consent was obtained from participants prior to data
176 collection.

177

178 *Preliminary visit and familiarisation trials*

179 Participants attended the laboratory on four separate occasions. The preliminary visit (1st visit) was used
180 to assess $\dot{V}O_{2\max}$, once body mass and stature were determined (DPS-Promatic srl via Edison 21 47122,
181 Forlì, Italy). A graded ramp test was completed until volitional exhaustion, which commenced at 10

182 km·h⁻¹, increasing by 1 km·h⁻¹ every 30 seconds, until 17 km·h⁻¹ was reached, at which point the gradient
183 was increased by 0.5% at each 30 second interval. A 72-hour period then separated the 1st visit from the
184 familiarisation trial (2nd visit). This visit involved a full habituation of all experimental procedures
185 including the full 120 min of soccer-specific exercise, and the completion of a standardised, treadmill-
186 based warm-up (~10 min). This comprised intermittent changes in speeds and a dynamic stretching
187 sequence as dynamic stretching has acute ergogenic effects on sprint and jump performance, versus
188 static stretching (Needham, Morse & Degens, 2009). Thereafter, main trial 1 (3rd visit) was performed,
189 followed by main trial two (4th visit). The familiarisation and both main trials were interspersed by
190 seven days to ensure full recovery. Identical procedures were followed for main trials one and two to
191 assess the reliability of the mechanical and physiological responses and all other data are presented from
192 main trial 2.

193

194 *Main trial procedures*

195 Participants were asked to record and replicate dietary intake for both main trials commencing 24 h
196 prior until completion of exercise. Both main trials were conducted at the same time of day to minimise
197 the effects of circadian variation. Upon arrival at the laboratory, a mid-flow urine sample was provided
198 to measure urine osmolality (Osmocheck, Vitech Scientific, West Sussex, UK). A blood sample was
199 then taken at rest followed by an assessment of body mass and stature. The warm-up, as reported above,
200 was completed, and 200 ml of water consumed. Measurements of countermovement jump height (CMJ)
201 proceeded the warm-up, followed by a five min passive rest period. The quantity of water administered
202 was standardised and provided at half-time (HT; 500 ml), full-time (FT; 300 ml) and during the two
203 min interval (200 ml) separating ET as per previous investigations (Harper et al., 2016b). Assessments
204 of CMJ and body mass were taken upon completion, immediately followed by an assessment of urine
205 osmolality to determine hydration status; euhydration was accepted as <600 mOsm·kg⁻¹ (Hillman et al.,
206 2013). Urine-corrected mass changes were calculated for body mass assessment.

207

208 *Soccer simulation*

209 A modified version of 90 min of soccer-specific exercise (Page, Marrin, Brogden, Greig, et al., 2015)
210 was performed on a motorised treadmill (h/p/ cosmos pulsar® 3p: h/p/cosmos sports & medical GmbH,
211 Nussdorf, Germany). It comprised of two 45 min halves interspersed by a 15 min passive recovery
212 break (HT), followed by a five min passive rest period, and a further two 15 min periods (ET), separated
213 by two min passive recovery. Similar to previous research (Harper et al., 2016b), the soccer-specific
214 exercise was performed in 15 min blocks (with data assessed likewise). The changes in speed were set
215 at the treadmill limit ($1.39 \text{ m}\cdot\text{s}^{-2}$) and players reached maximal speeds of $25 \text{ km}\cdot\text{h}^{-1}$ during the soccer-
216 specific exercise (Fig 1). This soccer-specific exercise was designed to simulate the durations,
217 intensities and the velocity profile of match-play based on previous notational analyses (Mohr et al.,
218 2003). The participants covered a distance of 16.26 km (similar to actual match-play; (Winder et al.,
219 2018) during the soccer-specific exercise with blood capillary samples, and d-RPE provided at the end
220 of each 15 min bout of activity. Mean values for RER, $\dot{V}\text{O}_2$ and HR, and PL data were taken as an
221 average across each 15 min block of exercise.

222

223 *****INSERT FIG 1*****

224

225 *Experimental measures*

226 Respiratory flow volumes were recorded continuously throughout the trial using a volume transducer
227 (Triple® V, Cortex, Germany) and breath-by-breath automated gas analysis system (Metamax® 3B-R2,
228 Cortex, Germany). Thereafter, individual mean ($\dot{V}\text{O}_{2\text{mean}}$) values were expressed as average O_2 intake
229 across each 15 min bout and the highest value reached was defined as $\dot{V}\text{O}_{2\text{peak}}$. Additionally, respiratory
230 exchange ratio (RER) was calculated from the proportion of CO_2 produced and O_2 consumed through
231 use of the manufacturer software equation (Metasoft®Studio Cortex, Germany; Wasserman et al., 1987)
232 and defined as the mean over each 15 min bout of the trial.

233

234 The treadmill automatically paused at the end of each 15 min block of exercise and a finger-tip blood
235 capillary sample was taken before being manually resumed and sample was analysed for BLa (Biosen
236 C-Line; EKF-diagnostic GmbH, Cardiff, Wales). In addition, d-RPE was provided through use of the

237 Borg 15-point (6-20) linear scale (Borg, 1998) and participants were asked to differentiate between
238 RPE-L, RPE-B and RPE-O for each 15 min block of activity. To eliminate order effects, these values
239 were collected in a counterbalanced order. CMJ height was measured using two portable photoelectric
240 cells (Optojump, Italy) and was calculated using Optojump software. The jumps were separated by a
241 10 s passive rest interval for each of five respective time-points (rest, post HT, pre second-half, 90 min
242 and 120 min). Participants were instructed to jump with hands on hips to nullify the influence of
243 momentum; the mean of three jumps were presented for analysis.

244

245 A portable accelerometer (Kionix KX94, Kionix, Ithaca, New York, USA), housed inside a GPS unit
246 (OptimEye S5, Catapult Innovations, Scoresby, Australia) was used to measure tri-axial PL (PL_{Total}) at
247 a sampling frequency of 100 Hz. Participants were assigned the same unit for each trial to avoid inter-
248 unit variation, as the Catapult OptimEye S5 device has been shown to possess high intra-unit reliability,
249 yet inconsistent inter-unit reliability (Nicolella et al., 2018). A tight-fitted neoprene garment was worn
250 to secure the device, housed in-between the scapulae to limit movement artefacts. A HR sensor (Polar
251 H10, Polar USA, United States) was synchronised with the GPS unit, attached directly to the vest *via* a
252 snap fastener and worn inferior to the sternum to quantify both mean (HR_{mean}) and max (HR_{max}) HR
253 values; HR_{max} was defined as the peak value recorded during a given 15 min exercise bout. Uni-axial
254 PlayerLoadTM was determined for each movement plane (vertical [PL_V], anterior-posterior [PL_{A-P}] and
255 medial-lateral [PL_{M-L}]). Participant PL_{Total} values were derived from the summation of the
256 aforementioned planes of motion. The relative contributions of the uni-axial vectors were calculated
257 ($PL_V\%$, $PL_{A-P}\%$ and $PL_{M-L}\%$) for the percentage contributions to PL_{Total} . All PL data were expressed as
258 arbitrary units (au) and defined across each 15 min period of soccer exercise.

259

260 *Statistical analyses*

261 Data were analysed using both Statistical Package for the Social Sciences (IBM SPSS Statistics 24 for
262 windows; SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p \leq 0.05$ prior to analyses.
263 All data were expressed as mean \pm standard deviation, unless indicated otherwise. An *a priori* power
264 analysis (GPower v3.1; Germany) deemed a sufficient sample size of 11 based on $\geq 80\%$ power

265 $(1 - \beta)$, an alpha (α) of 0.05 and a medium effect size ($d = 0.5$) based on previous PL_{Total} data (Page et
266 al., 2019). Normal distribution of data and variance homogeneity between each 15 min interval were
267 assessed using Shapiro–Wilk and a Levene’s test, respectively.

268 The data were divided into the following epochs: E1 (00:00–14:59 min), E2 (15:00–29:59 min), E3
269 (30:00–44:59 min), E4 (45:00–59:59 min), E5 (60:00–74:59 min), E6 (75:00–89:59 min), E7 (90:00–
270 104:59 min) E8 (105:00–119:59 min). A repeated measures analysis of variance was used to
271 determine the effect of time for each outcome. To control for family-wise error, post-hoc pairwise
272 comparisons were applied using the Bonferroni correction method. In accordance with Hopkins
273 (2000), test-retest reliability was established using typical error (TE) and coefficient of variation (CV)
274 for absolute reliability, and Pearson’s correlation coefficient (r) for relative reliability. For CV, $<10\%$
275 was accepted as good absolute reliability (Atkinson & Nevill, 1998) and thresholds for r were
276 considered moderate (0.3–0.5), strong (0.5–0.7), and very strong (>0.7) (Hopkins, 2000). Effect sizes
277 (ES) were calculated using Cohen’s d and were categorised as small (0.2), medium (0.5), and large
278 (0.8) (Fritz, Morris & Richler, 2012).

279

280 **Results**

281 All participants were presented for data analysis, except for one participant for ventilatory values (owing
282 to claustrophobia) and another for the blood analyses (due to haemophobia), albeit the remainder of
283 their data was used.

284

285 *PlayerLoad responses throughout 120 minutes of soccer exercise*

286 As highlighted in Table 1, a main effect for time was observed for PL_{Total} ($p = 0.045$) with post-hoc
287 analyses revealing that values were higher during E8 compared to E1 ($+9.9 \pm 5.3\%$; $p = 0.002$; $d = 0.8$;
288 Fig 2). Likewise, a main effect for time was found for PL_V ($p = 0.002$) with significant increases
289 observed during E8 (118 ± 19 a.u) compared to E1 (111 ± 16 a.u). In addition, main effects for time
290 were identified for PL_{A-P} ($p = 0.011$) with significance identified between E1 (53 ± 7 a.u) and E8 ($60 \pm$
291 5 a.u). No time effects were established for PL_{M-L} ($p = 0.074$), $PL_{V\%}$ ($p = 0.703$), $PL_{A-P\%}$ ($p = 0.835$) or
292 $PL_{M-L\%}$ ($p = 0.463$).

293

294 *Physiological and physical responses throughout 120 minutes of soccer exercise*

295 Significant main effects for time were evident for RER ($p = 0.001$) with decreases observed during E8
296 (0.87 ± 0.03 a. u) compared to E1 (0.92 ± 0.02 a.u). Additionally, HR_{mean} demonstrated a main effect
297 for time ($p = 0.003$), with differences identified between E3 ($159 \pm 16 \text{ b}\cdot\text{min}^{-1}$) and E4 ($152 \pm 16 \text{ b}\cdot\text{min}^{-1}$;
298 $p \leq 0.001$), as well as E4 and E5 ($159 \pm 16 \text{ b}\cdot\text{min}^{-1}$; $p = 0.003$). No main effects for time were observed
299 for $\dot{V}O_{2\text{mean}}$ ($p = 0.407$), $\dot{V}O_{2\text{peak}}$ ($p = 0.879$), HR_{peak} ($p = 0.959$) or BLa ($p = 0.203$). As outlined in Table
300 2, a main effect of time for both RPE-L ($p = 0.001$) and RPE-O ($p = 0.003$) was found. For RPE-L, a
301 significant increase was detected from E1 (11 ± 1) to E8 (17 ± 1 ; $p \leq 0.001$) and a similar pattern was
302 evident for RPE-O between E1 (11 ± 1) and E8 (17 ± 2 ; $p \leq 0.001$). No main effects were observed for
303 RPE-B ($p = 0.076$). Main effects for time were established for CMJ ($p = 0.020$), however, post-hoc
304 comparisons revealed no differences between time points.

305

306 No differences were detected for urine osmolality pre ($610 \pm 132 \text{ mOsmoL} \cdot \text{kg}^{-1}$) and post (586 ± 135
307 $\text{mOsmoL} \cdot \text{kg}^{-1}$; $p = 0.985$) trial. Once urine-corrected, no changes in mass were identified from pre
308 ($70.5 \pm 8.8 \text{ kg}$) to post ($69.4 \pm 8.5 \text{ kg}$; $p = 0.928$) trial.

309

310 *****INSERT FIG 2*****

311 *****INSERT TABLE 1*****

312

313 *Reliability of biomechanical, physiological and physical responses*

314 All PL variables across all time points demonstrated a significant, very strong r , except for E1 and E2
315 for $PL_{\text{M-L}\%}$. All CV's were $<8\%$ for all PL metrics across each time point (Table 1). For RER, moderate
316 to very strong ($r = 0.33-0.72$) correlations were observed during each epoch of which E4, E6, E7 and
317 E8 displayed significance ($p \leq 0.05$). All CVs for RER were $<4\%$ irrespective of time point. All time
318 points for $\dot{V}O_{2\text{mean}}$ and $\dot{V}O_{2\text{peak}}$ (except for E8 for $\dot{V}O_{2\text{mean}}$; E5 and E6 for $\dot{V}O_{2\text{peak}}$) were >0.70 (r),
319 however, both demonstrated good ($<7\%$) CVs. For all epochs, the CV values were lower than 10% and
320 strong and very strong ($r = 0.51-0.75$) relationships were found between trials for HR_{mean} . Majority of

321 CVs were >10% for HR_{peak} except E1, E4 and E6, and r was less than 0.3 for all epochs excluding E1
322 and E6. All CVs were <3% for d-RPE values, and RPE-L and RPE-B demonstrated moderate to very
323 strong (0.39-0.88) relationships for all time points except for RPE-L during E2 (0.29) and RPE-B for
324 E4 (0.34). Although RPE-O demonstrated moderate to very strong relationships for six out of eight time
325 points (E1, E4-E8; $r = 0.45-0.9$), all CVs were <3% throughout the trial (refer to Table 2 for
326 significance). Average CVs for CMJ were ~1%, and very strong, significant correlations were detected
327 (>0.9; r). CVs were <10% for BLA and only two time points for r values were identified as significant
328 ($p \leq 0.05$).

329

330 ***INSERT TABLE 2 ***

331

332 Discussion

333 The aim of this study was to investigate the biomechanical and physiological responses to a 120 min of
334 treadmill-based soccer-specific exercise. In accordance with our hypotheses, biomechanical
335 performance was negatively impacted as a function of time, with further reductions in efficiency
336 identified for PL_{Total} during the final 30 min of exercise. Furthermore, increases in d-RPE and the rate
337 of fat oxidation were observed during ET. Furthermore, the test-retest reliability for most of the
338 variables was moderate to very strong for relative reliability (i.e., r) and good for absolute reliability
339 (i.e., CVs).

340

341 To date, evidence suggests that the physical capacity of players is reduced during ET matches (Peñas,
342 Dellal, Owen & Gómez-Ruano, 2015; Russell et al., 2015; Winder et al., 2018). However caution
343 should be applied when interpreting match-play observations as they do not account for contextual
344 variables (Abbott, Brownlee, Harper, Naughton & Clifford, 2018) such as stoppages in play and
345 altered tactical approaches. However, in the present study, the use of a treadmill simulation enabled
346 the standardisation of workload, thus allowing for any observed changes to be attributable to changes
347 in a player's capacity to cope with the work rate, and as such, any observed changes in PL can be

348 attributable to changes in movement efficiency rather than modifications to the activity and
349 locomotion profile performed (Page et al., 2015).

350 Page et al. (2015) assessed PL responses across 90 min of treadmill-based, soccer-specific bouts of
351 fixed, identical bouts of repeated activity. The authors reported increases in PL_{Total} , concurrent with
352 reductions in $PL_{V\%}$ as a function of exercise duration. Similarly, previous match-play observations
353 found a reduction in the vertical contribution of PL in Australian rules football players (Cormack et al.,
354 2013). Consistent with the two studies above, our data suggests a similar temporal pattern, which,
355 although not directly measured in the current study, may be indicative of an attempt to conserve energy
356 by adjusting stride length or frequency, or both, which could in turn reduce running efficiency (Hobara
357 et al., 2010). It appears that when fatigued, individual running patterns become biomechanically less
358 efficient, which can cause additional stress to joints, tendons and ligaments (Wilk, Nau & Valero, 2009).
359 Furthermore, the modifications in vertical movement as seen in the present research have previously
360 been associated with reductions in lower extremity stiffness (Buchheit, Gray & Morin, 2015).

361

362 Although the relationship between stiffness and injury is not well established, it is believed that
363 disproportionate levels of stiffness can lead to an increased injury-risk to the lower extremities (Butler,
364 Crowell, & Davis, 2003). From our data it can be speculated that participants displayed less vertical
365 displacement as a function of exercise duration, indicative of a reduced vertical stiffness and increased
366 risk to soft tissues (Hughes & Watkins, 2008). However, during matches, it is likely that in a
367 subconscious attempt to avoid injury, players will reduce work rate, in turn impacting physical
368 performance. In further support of a potential reduction in performance, impaired movement efficiency
369 may also manifest in a reduced ability to maintain high intensity output, with this in turn reducing a
370 team's ability to score goals. To support this suggestion, it has been suggested previously by Faude et
371 al., (2012) that 45% of goals in the German Bundesliga were preceded with straight line sprints.
372 Therefore, a reduced capacity during ET may result in fewer matches decided during this period and as
373 such, preparing players for the additional 30 min duration associated with ET may reduce injury-risk
374 and increase physical performance, ultimately increasing team success.

375

376 Another novel feature of this study was the measurement of substrate utilisation *via* gas analysis (i.e.,
377 RER) across 120 min of soccer-specific exercise. An RER of 1.0 indicates 100% CHO oxidation (i.e.,
378 glycolysis), whilst a value of 0.70 indicates 100% fatty acid oxidation (i.e., lipolysis), with 0.85 a.u
379 indicating an equal contribution. According to the current data and corresponding with previous ET
380 research (Stevenson et al., 2017), players utilise both fat and CHO to fuel soccer exercise, however, fat
381 oxidation increases during ET. Despite observing a shift in the direction of lipolysis and a
382 downregulation in glycolysis, we are cognizant that our RER values during ET (0.87 a.u) suggest that
383 CHO is still being utilised. Furthermore, as participants were less efficient (i.e., increased energy cost
384 to produce the same activity) across bouts, it was surprising to find a ~29% reduction (although non-
385 significant) in BLa concentrations between E6 and E7 (Fig 3). This further supports that glucose levels
386 were potentially depleted and less was available to undergo biotransformation during ET as under
387 anaerobic conditions, BLa is the final product of glycolysis.

388 *****INSERT FIG 3*****

389 Prior to the main trials, participants in the current research were not required to consume a pre-match
390 meal as done in a previous investigation that has attempted to measure changes in substrate use
391 (Stevenson et al., 2017). Therefore, this methodological discrepancy limits comparison between studies
392 as participants in the current study may have completed exercise with lesser endogenous CHO at
393 baseline. Furthermore, within-match CHO consumption is customary for soccer players (Anderson et
394 al., 2016) and participants in the present research were limited to water intake. Evidence shows that
395 exercising without exogenous CHO ingestion results in inherent increases in the oxidation of plasma
396 FFA (Gribok et al., 2016), however this is largely influenced by exercise intensity and duration, among
397 other factors (van Loon, Greenhaff, Constantin-Teodosiu, Saris & Wagenmakers, 2001). Accordingly,
398 further investigations examining the effect of CHO supplementation across 120 min of soccer-specific
399 exercise are warranted.

400

401 The present results indicate that the soccer-specific exercise imposed the most considerable load on
402 RPE- L with scores reaching 17 ± 1 during ET, equating to the verbal anchor 'very hard' according to
403 the Borg scale. This finding is consistent with other work whereby RPE-L was highest during aerobic
404 exercise (Borg et al., 2010) and ~ 30 min post soccer match-play (Weston et al., 2015). However, given
405 this study is the first to employ a within soccer-specific exercise approach to measuring d-RPE, it is
406 difficult to compare our findings directly to other literature; therefore, this research may be used to
407 inform future investigation that measures within-match changes in d-RPE. Furthermore, d-RPE
408 typically increased as a function of exercise duration and was reliable between sessions ($CV \leq 2.1\%$).
409 This suggests that d-RPE can be used to reliably assess internal load during soccer-specific exercise
410 and may be a feasible tool to differentiate player exertion to assist in tailoring training programmes
411 (Macpherson et al., 2019).

412

413 The test re-test responses to the current soccer-specific exercise simulation were moderate to strong.
414 Previous convergent validity analysis by Berreira and colleagues assessing two sessions of a free-
415 running soccer match simulation demonstrated higher CVs for PL (14.5-24.5%) (Barreira et al., 2017)
416 compared with the current study ($PL_{Total} = 2.8-5\%$). Considering the increased reliability of responses
417 elicited during soccer exercise performed on treadmills, the current simulation may be preferable
418 compared with free-running protocols such as the Soccer Match Simulation (Harper et al., 2016b),
419 especially if researchers have logistical issues, such as limited space. That said, skill performance is
420 also impacted by exercise duration (Russell & Kingsley, 2011) and it must be noted that treadmills are
421 limited concerning the incorporation of technical actions. Therefore, if researchers are interested in
422 assessing physical and physiological responses of players across 120 min of soccer-specific exercise,
423 the current simulation may be desirable.

424

425 Within the scope of the limitations, the findings of the current study add to an expanding body of
426 literature that has thus far, failed to quantify the biomechanical demands and substrate usage estimated
427 through the use of gaseous exchange during ET. To conclude, our data show a temporal shift in
428 predominant energy pathway utilisation (i.e., aerobic glycolysis to fat oxidation) during 120 min of

429 soccer exercise. Likewise, changes in PL throughout 120 min of soccer-specific exercise were evident,
430 with further fatigue-induced changes identified during ET.

431

432 **What does this article add?**

433 This study took a novel approach to investigating soccer-specific exercise over 120 min, that is, utilising
434 standardised periods of workload to assess fatigue responses. Based on these findings, we postulate that
435 the reduced mechanical efficiency observed may hold fatigue-induced injury-risk implications for
436 players during this period of match-play. However, the extent to which the additional demands
437 associated with ET contribute to injury prevalence may be required through the longitudinal
438 surveillance of soccer players. It is recommended that practitioners condition players to be able to cope
439 with this additional workload associated with an additional 30 min to reduce potential injury occurrence,
440 although the contemporary issue of fixture congestion may limit time to do so. Therefore, at which stage
441 during the season this is developed and maintained must be considered. This research also confirms the
442 importance of CHO consumption during soccer matches to maintain the glycolytic process, which may
443 assist with offsetting the impact of fatigue. Finally, FIFA now authorise a fourth substitution during ET
444 and as such, utilising replacements during this period may be efficacious to reduce the deleterious effect
445 that fatigue may have on player performance.

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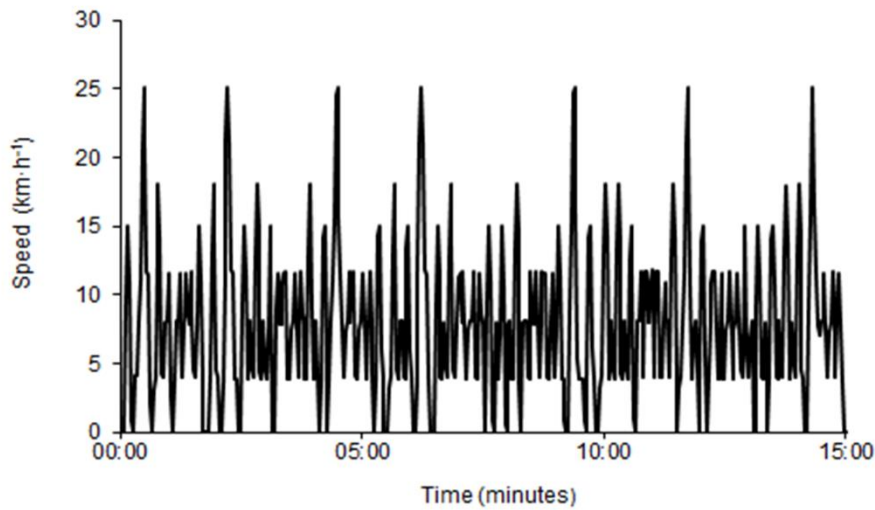
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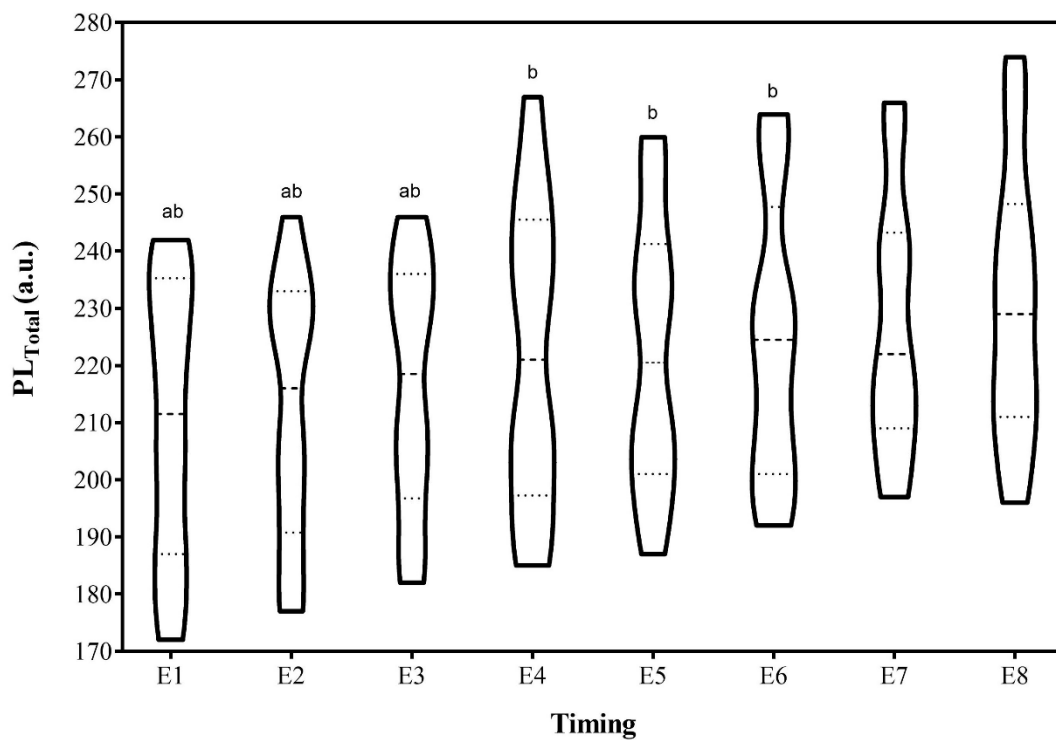
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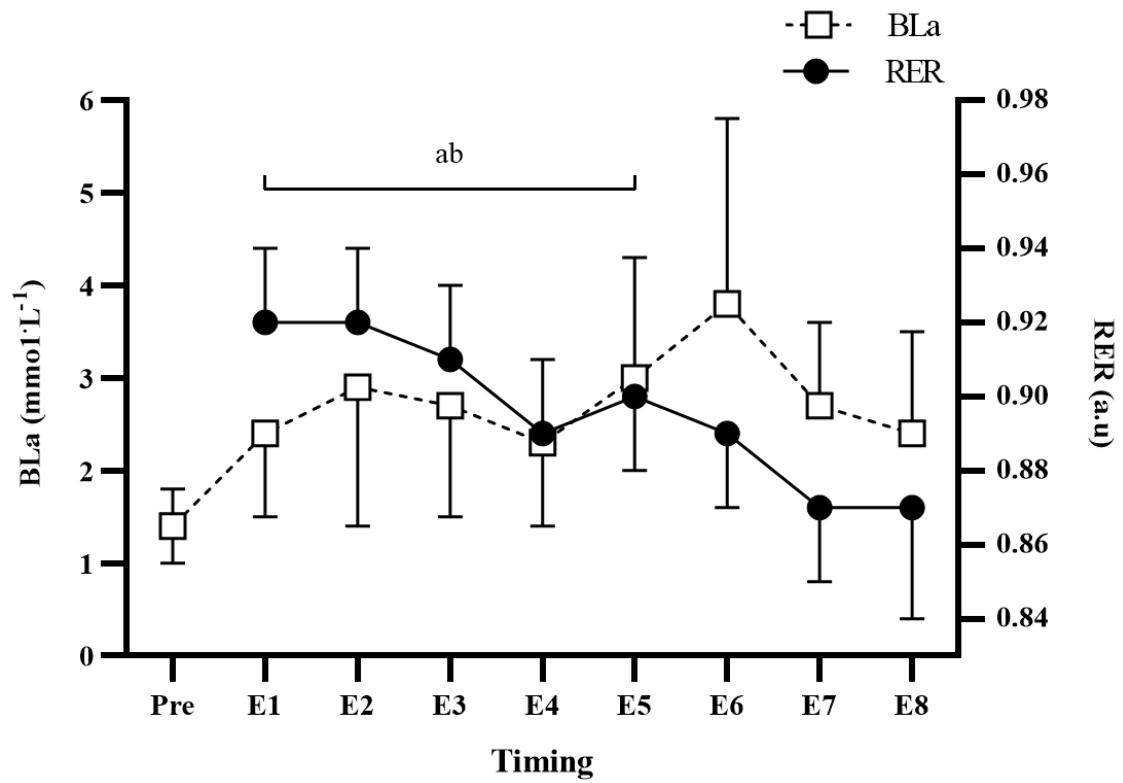
648 **Fig 1** A schematic of an individual 15-minute bout of the soccer-specific exercise

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651 **Fig 2** This graph shows the time history changes in PL_{Total} response throughout 120 min of soccer-
 652 specific exercise. Data are expressed as mean \pm SD. a denotes significant difference from E7 for
 653 PL_{Total} b denotes significant difference from E8 for PL_{Total} (both $p \leq 0.05$)



655

656 **Fig 3** Mean RER and BLa concentrations across 120 min for each 15 min period of soccer-specific
657 exercise. Data are expressed as mean \pm SD. a denotes significant difference from E7 for RER. b
658 denotes significant difference from E8 ($p \leq 0.05$) for RER.

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Table 1. Biomechanical responses throughout 120 min of soccer-specific exercise (mean \pm SD)

Variable	Time							
	E1	E2	E3	E4	E5	E6	E7	E8
PL_{Total} (a.u)								
Trial 1	208 \pm 27	213 \pm 28	217 \pm 28	217 \pm 27	219 \pm 26	220 \pm 25	225 \pm 22	227 \pm 23
Trial 2	215 \pm 25 ^{gh}	216 \pm 23 ^{gh}	220 \pm 22 ^{gh}	226 \pm 27 ^h	226 \pm 24 ^h	229 \pm 25 ^h	230 \pm 23 ^{abc}	234 \pm 24 ^{abcdef}
Mean	209 \pm 25	212 \pm 24	217 \pm 24	220 \pm 26	220 \pm 24	222 \pm 24	226 \pm 22	229 \pm 23
CV (%)	5	4.7	4.3	4.1	3.7	2.8	3	3.2
<i>r</i>	0.84*	0.86*	0.9*	0.9*	0.91*	0.95*	0.92*	0.91*
TE	11.05	10.28	9.5	9.1	8.06	6.15	6.67	7.44
PL_V (a.u)								
Trial 1	110 \pm 19	112 \pm 21	112 \pm 21	113 \pm 21	113 \pm 21	113 \pm 21	116 \pm 19	116 \pm 20
Trial 2	111 \pm 16 ^h	111 \pm 16	113 \pm 15	116 \pm 20	115 \pm 18 ^g	116 \pm 19	117 \pm 18	118 \pm 19 ^a
Mean	110 \pm 17	111 \pm 18	112 \pm 18	115 \pm 20	114 \pm 19	115 \pm 19	116 \pm 18	117 \pm 19
CV (%)	4.9	5.5	5.7	4.3	4.1	2.1	2.2	2.4
<i>r</i>	0.91*	0.9*	0.91*	0.95*	0.96*	0.98*	0.98*	0.97*
TE	5.76	6.89	6.91	4.96	4.66	3.1	2.87	3.47
PL_{A-P} (a.u)								
Trial 1	52 \pm 8	54 \pm 7	55 \pm 7	55 \pm 8	57 \pm 7	58 \pm 7	58 \pm 7	60 \pm 7
Trial 2	53 \pm 7 ^{gh}	53 \pm 7 ^{gh}	55 \pm 7 ^{gh}	56 \pm 8	57 \pm 6 ^h	58 \pm 6 ^h	59 \pm 6 ^{abc}	60 \pm 5 ^{abcef}
Mean	52 \pm 7	54 \pm 7	55 \pm 7	56 \pm 7	57 \pm 6	58 \pm 6	58 \pm 6	60 \pm 6
CV (%)	6	4.8	3.3	5	4.6	4.3	4	4.9
<i>r</i>	0.86*	0.88*	0.94*	0.9*	0.88*	0.84*	0.89*	0.9*
TE	3.11	2.62	1.87	2.62	2.45	2.27	2.1	2.3
PL_{M-L} (a.u)								
Trial 1	47 \pm 6	47 \pm 6	48 \pm 6	49 \pm 6	49 \pm 6	49 \pm 6	51 \pm 6	51 \pm 6
Trial 2	47 \pm 7 ^h	48 \pm 7 ^{gh}	49 \pm 7 ^{gh}	50 \pm 7	50 \pm 7 ^h	50 \pm 7 ^a	51 \pm 7 ^{bc}	52 \pm 8 ^{abce}
Mean	47 \pm 6	47 \pm 6	49 \pm 6	49 \pm 6	49 \pm 6	50 \pm 6	51 \pm 6	52 \pm 7
CV (%)	7.5	6.1	5.7	5.2	5.4	5.2	4.8	5.2
<i>r</i>	0.75*	0.82*	0.84*	0.85*	0.85*	0.87*	0.89*	0.9*
TE	3.5	2.85	2.79	2.58	2.6	2.61	2.44	2.65
PL_{V%}								
Trial 1	52 \pm 4	52 \pm 4	52 \pm 4	52 \pm 4	52 \pm 4	51 \pm 4	51 \pm 4	51 \pm 4
Trial 2	53 \pm 3	52 \pm 3	52 \pm 3	52 \pm 4	52 \pm 4	52 \pm 4	51 \pm 4	51 \pm 4

Mean	52 ± 3	52 ± 3	52 ± 4	52 ± 4	52 ± 4	51 ± 4	51 ± 4	51 ± 4
CV (%)	1.8	2.5	1.9	1.5	2.1	1.4	0.9	1.6
<i>r</i>	0.94*	0.88*	0.95*	0.96*	0.95*	0.98*	0.99*	0.99*
TE	0.95	1.34	1.05	0.82	1.09	0.7	0.47	0.77
PL _{A-P} %								
Trial 1	25 ± 4	26 ± 3	26 ± 4	26 ± 4	26 ± 4	27 ± 4	26 ± 4	27 ± 4
Trial 2	25 ± 3 ^h	26 ± 3	26 ± 3	26 ± 3	26 ± 3	26 ± 3	26 ± 3	26 ± 3 ^a
Mean	25 ± 3	26 ± 3	26 ± 3	26 ± 3	26 ± 3	26 ± 3	26 ± 3	26 ± 3
CV (%)	4.6	3.5	3.2	4.5	3.2	3.7	2.9	2.5
<i>r</i>	0.92*	0.95*	0.96*	0.95*	0.96*	0.97*	0.96*	0.98*
TE	1.05	0.85	0.79	1.02	0.82	0.87	0.79	0.68
PL _{M-L} %								
Trial 1	22 ± 2	22 ± 2	22 ± 2	22 ± 2	22 ± 2	22 ± 2	23 ± 2	23 ± ± 2
Trial 2	22 ± 1	22 ± 2	22 ± 2	22 ± 1	22 ± 1	22 ± 1	23 ± 1	23 ± 1
Mean	22 ± 1	22 ± 2	22 ± 2	22 ± 2	22 ± 2	22 ± 2	23 ± 2	23 ± 2
CV (%)	5	4.9	4.1	3.5	3	2.8	2.3	1.9
<i>r</i>	0.46	0.56	0.71*	0.84*	0.88*	0.86*	0.94*	0.96*
TE	1.1	1.08	0.93	0.82	0.64	0.67	0.52	0.43

Note. PL_{Total} = tri-axial playerload; PL_V = vertical playerload; PL_{A-P} = anterior/posterior playerload; PL_{M-L} = medial/lateral playerload; $PL_{V\%}$ = Percentage contribution of vertical vector; $PL_{A-P\%}$ = percentage contribution of anterior/posterior vector; $PL_{M-L\%}$ = percentage contribution of medial/lateral vector; a.u = arbitrary units; CV = coefficient of variation (%); *r* = Pearson's correlation coefficient; TE = typical error; E1 = 00:00–14:59 min, E2 = 15:00–29:59 min, E3 = 30:00–44:59 min, E4 = 45:00–59:59 min, E5 = 60:00–74:59 min, E6 = 75:00–89:59 min, E7 = 90:00–104:59 min and E8 = 105:00–119:59 minutes; mean = mean of both trial 1 and 2. Significant differences are only reported for trial 2.

^{a-h} Denotes significance from E1-E8 ($p \leq 0.05$), respectively.

* Denotes significance for Pearson's correlation coefficient for specified time points between trials ($p \leq 0.05$).

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Table 2. Physiological responses throughout 120 min of soccer-specific exercise (mean \pm SD)

Variable	Time							
	E1	E2	E3	E4	E5	E6	E7	E8
RER (a.u)								
Trial 1	0.93 \pm 0.03	0.92 \pm 0.02	0.92 \pm 0.02	0.90 \pm 0.03	0.91 \pm 0.02	0.89 \pm 0.03	0.88 \pm 0.02	0.88 \pm 0.03
Trial 2	0.92 \pm 0.02 ^{gh}	0.92 \pm 0.02 ^{gh}	0.91 \pm 0.02 ^{gh}	0.89 \pm 0.02 ^{gh}	0.90 \pm 0.02 ^{gh}	0.89 \pm 0.02 ^h	0.87 \pm 0.02 ^{abcde}	0.87 \pm 0.02 ^{abcdef}
Mean	0.93 \pm 0.03	0.92 \pm 0.02	0.91 \pm 0.02	0.90 \pm 0.02	0.91 \pm 0.02	0.89 \pm 0.02	0.88 \pm 0.02	0.87 \pm 0.03
CV (%)	2.9	2.1	2.2	2.9	2.6	2.7	2.1	3.2
<i>r</i>	0.33	0.47	0.42	0.65*	0.52	0.71*	0.72*	0.67*
TE	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02
$\dot{V}O_{2\text{mean}}$ (ml·kg⁻¹·min⁻¹)								
Trial 1	35 \pm 4	34 \pm 5	35 \pm 5	34 \pm 5	34 \pm 5	34 \pm 5	34 \pm 5	34 \pm 5
Trial 2	34 \pm 4	34 \pm 4	34 \pm 5	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	33 \pm 4
Mean	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4
CV (%)	2.1	2.1	1.9	1.4	1.6	1.6	1.3	2.4
<i>r</i>	0.78*	0.8*	0.85*	0.9*	0.88*	0.87*	0.91*	0.67*
TE	2.07	2.06	1.88	1.41	1.59	1.63	1.3	2.35
$\dot{V}O_{2\text{peak}}$ (ml·kg⁻¹·min⁻¹)								
Trial 1	35 \pm 4	34 \pm 5	35 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4
Trial 2	34 \pm 4	34 \pm 4	34 \pm 5	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	33 \pm 4
Mean	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4	34 \pm 4
CV (%)	4.4	4.1	5.7	5.4	5.5	6.3	3.2	4
<i>r</i>	0.85*	0.9*	0.79*	0.79*	0.64*	0.29	0.85*	0.75*
TE	4.29	4.06	5.58	5.22	5.32	6.15	3.61	3.9
HR_{mean} (b·min⁻¹)								
Trial 1	154 \pm 17	157 \pm 19	160 \pm 21	152 \pm 18	157 \pm 22	157 \pm 22	160 \pm 20	163 \pm 18
Trial 2	150 \pm 13	154 \pm 16	159 \pm 16 ^d	152 \pm 16 ^{ce}	157 \pm 16 ^d	157 \pm 16	157 \pm 15	159 \pm 16
Mean	152 \pm 15	155 \pm 17	159 \pm 18	152 \pm 17	157 \pm 18	157 \pm 19	158 \pm 17	161 \pm 17
CV (%)	3.2	6.2	8.8	8.6	8.9	7.2	7.7	5.7
<i>r</i>	0.91*	0.77*	0.56	0.53	0.59	0.75*	0.61*	0.77*
TE	9.18	9.08	12.84	12.18	13.01	10.68	11.61	8.74
HR_{peak} (b·min⁻¹)								
Trial 1	186 \pm 26	179 \pm 21	179 \pm 21	171 \pm 22	173 \pm 21	181 \pm 24	178 \pm 23	183 \pm 24
Trial 2	179 \pm 18	176 \pm 19	176 \pm 20	175 \pm 18	178 \pm 23	175 \pm 17	180 \pm 16	185 \pm 15
Mean	182 \pm 22	177 \pm 19	177 \pm 20	173 \pm 19	175 \pm 21	178 \pm 20	179 \pm 19	184 \pm 20

CV (%)	6	10.2	11	9.9	11.5	9.1	10.6	11.7
<i>r</i>	0.85	0.24	0.19	0.28	0.17	0.43	0.16	-0.02
TE	10.79	17.56	18.79	17	20.01	16.09	18.36	20.3
BLa (mmol · L ⁻¹)								
Trial 1	2.4 ± 1.0	2.4 ± 1.0	2.1 ± 0.6	2.2 ± 1.2	2.5 ± 1.2	2.6 ± 1.2	2.2 ± 1.0	2.4 ± 1.0
Trial 2	2.4 ± 0.9	2.9 ± 1.5	2.7 ± 1.2	2.3 ± 0.9	3.0 ± 1.3	3.8 ± 2.7	2.7 ± 0.9	2.4 ± 1.1
Mean	2.4 ± 0.9	2.6 ± 1.2	2.4 ± 0.9	2.4 ± 1.0	2.8 ± 1.2	3.3 ± 2.1	2.6 ± 0.9	2.4 ± 1.0
CV (%)	0.8	0.9	0.7	0.5	0.7	1.8	0.6	0.6
<i>r</i>	0.6	0.41	0.12	0.46	0.89*	0.63*	0.32	0.59
TE	0.77	0.94	0.7	0.51	0.67	1.78	0.57	0.6
RPE-L (a.u)								
Trial 1	11 ± 1	11 ± 1	12 ± 1	13 ± 1	14 ± 1	15 ± 1	15 ± 1	17 ± 1
Trial 2	11 ± 1 ^{gh}	11 ± 1 ^{gh}	12 ± 1 ^{gh}	13 ± 1 ^{gh}	14 ± 1 ^{gh}	15 ± 1 ^{gh}	15 ± 1 ^{abcdeh}	17 ± 1 ^{abcdeh}
Mean	11 ± 1	11 ± 1	12 ± 1	13 ± 1	14 ± 1	15 ± 1	15 ± 1	17 ± 1
CV (%)	0.7	2.1	1.9	1.8	0.7	0.7	1.6	1.5
<i>r</i>	0.64*	0.29	0.61*	0.39	0.61*	0.87*	0.64*	0.78*
TE	0.64	0.77	0.51	0.82	0.74	0.41	0.68	0.59
RPE-B (a.u)								
Trial 1	11 ± 1	12 ± 1	12 ± 1	13 ± 1	14 ± 1	14 ± 1	15 ± 2	16 ± 2
Trial 2	11 ± 1 ^{gh}	12 ± 1 ^{gh}	12 ± 1 ^{gh}	13 ± 1 ^{gh}	14 ± 1	14 ± 1	15 ± 2 ^{abcd}	15 ± 2 ^{abcd}
Mean	11 ± 1	12 ± 1	12 ± 1	13 ± 1	14 ± 1	14 ± 1	15 ± 2	16 ± 2
CV (%)	0.7	1.8	0.7	0.7	0.7	0.7	1.5	0.7
<i>r</i>	0.75*	0.44	0.39	0.34	0.64*	0.68*	0.88*	0.86*
TE	0.55	0.84	0.77	0.96	0.82	0.84	0.76	0.86
RPE-O (a.u)								
Trial 1	11 ± 1	12 ± 1	13 ± 1	13 ± 1	14 ± 1	15 ± 1	14 ± 1	16 ± 1
Trial 2	11 ± 1 ^{gh}	11 ± 1 ^{gh}	12 ± 1 ^{gh}	13 ± 1 ^{gh}	14 ± 1 ^{gh}	15 ± 1 ^{gh}	15 ± 2 ^{abcdeh}	17 ± 2 ^{abcdeh}
Mean	11 ± 1	12 ± 1	12 ± 1	13 ± 1	14 ± 1	15 ± 1	16 ± 1	17 ± 1
CV (%)	2.1	0.7	0.7	0.7	0.7	0.7	1.4	0.7
<i>r</i>	0.84	0.17	0.22	0.9	0.45	0.84*	0.87*	0.9*
TE	1.04	0.93	0.77	1.06	0.77	0.47	0.56	0.47
	Pre trial	Post HT	Pre 2 nd half	90 min	120 min			
CMJ (cm)								
Trial 1	35.2 ± 6.3	36.0 ± 6.4	33.9 ± 6.8	36.5 ± 7.2	34.2 ± 8.5			
Trial 2	35.4 ± 7.1	36.5 ± 7.4	34.6 ± 7.9	36.8 ± 7.7	34.3 ± 8.4			

Mean	35.3 ± 6.4	36.2 ± 6.6	34.3 ± 7.1	36.6 ± 7.1	34.2 ± 8.1
CV (%)	0.8	0.7	1.1	0.9	0.7
<i>r</i>	0.93*	0.94*	0.92*	0.99*	0.99*
TE	1.96	1.98	2.27	0.8	1.04

Note. RER = respiratory exchange ratio; $\dot{V}O_2$ = oxygen consumption; HR = Heart rate; BLA = blood lactate; RPE = Ratings of perceived exertion; RPE-L = RPE legs; RPE-B = RPE breathlessness; RPE-O = RPE overall; CMJ = countermovement jump height; a.u = arbitrary units; CV = coefficient of variation (%); *r* = Pearson's correlation coefficient; TE = typical error; E1 = 00:00–14:59 min, E2 = 15:00–29:59 min, E3 = 30:00–44:59 min, E4 = 45:00–59:59 min, E5 = 60:00–74:59 min, E6 = 75:00–89:59 min, E7 = 90:00–104:59 min and E8 = 105:00–119:59 minutes; mean = mean of both trial 1 and 2. Significant differences are only reported for trial 2.

^{a-h} Denotes significant difference from E1-E8 ($p \leq 0.05$), respectively.

* Denotes significance for Pearson's correlation coefficient for specified time points between trials ($p \leq 0.05$).

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