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1

**Abstract**

2 PURPOSE: Professional football players experience both physical and mental fatigue. The  
3 main aims of this randomized crossover study were to investigate the effect of mental fatigue  
4 on repeated sprint ability (RSA), and the effects of both physical and mental fatigue on  
5 psychomotor vigilance. METHODS: Seventeen male professional football players performed  
6 10 maximal 20-m shuttle sprints interspaced by incomplete recovery (RSA test). Running  
7 speed, heart rate (HR), brain oxygenation and rating of perceived exertion (RPE) were  
8 monitored during each sprint. The RSA test was preceded by either a 30-min Stroop task to  
9 induce mental fatigue (MF), or by watching a documentary for 30 min (CON) in a randomized  
10 counterbalanced order. Participants performed a psychomotor vigilance test (PVT) at baseline,  
11 after the cognitive task (MF or CON), and after the RSA test. RESULTS: HR and RPE  
12 significantly increased, while running speed and brain oxygenation significantly decreased  
13 over the repeated sprints ( $p < 0.001$ ) with no significant differences between conditions.  
14 Response speed during the PVT significantly declined after the Stroop task but not after CON  
15 ( $p = 0.001$ ). Response speed during the PVT declined after the RSA test in both conditions ( $p$   
16  $< 0.001$ ) and remained lower in the MF condition compared to CON ( $p = 0.012$ ).  
17 CONCLUSIONS: Mental fatigue does not reduce RSA. However, the results of this study  
18 suggest that physical and mental fatigue have negative and cumulative effects on psychomotor  
19 vigilance. Therefore, strategies to reduce both physical and mental fatigue should be  
20 implemented in professional football players.

21

22 Keywords: soccer, physical performance, cognitive performance, repeated sprint ability,  
23 brain oxygenation

24

## Introduction

25 Professional football players experience a decline in various parameters of physical  
26 performance during the match <sup>1</sup>. Technical performance also declines as proved by a reduction  
27 in ball possession and; an increase in the number of unsuccessful passes <sup>2</sup>. A higher number of  
28 goals scored during the second half of the match is also observed<sup>3</sup>. Understanding the  
29 mechanisms of this match-related fatigue is important if we want to reduce its impact and  
30 further improve football performance.

31 Playing football induces significant neuromuscular and metabolic alterations that  
32 reduce the player's ability to produce force, speed and power <sup>1</sup>. In addition to this physical  
33 fatigue, playing football induces significant mental fatigue especially during congested fixtures  
34 <sup>4</sup>. This is not surprising because the game requires football players to react quickly, make  
35 important decisions, remember and switch plays and strategies, and remain vigilant throughout  
36 the whole match. Psychological stressors outside the game itself (e.g. frequent travelling and  
37 education) can also induce mental fatigue <sup>4</sup>.

38 Recent studies have experimentally investigated the effects of mental fatigue on  
39 different aspects of physical, technical, and cognitive performance in football players <sup>5-8</sup>. Smith  
40 and colleagues reported a decrease in football-specific measures of aerobic endurance capacity  
41 as well as passing and shooting ability <sup>5</sup>. These initial findings have been confirmed and  
42 expanded by other authors who reported impairments in dribbling accuracy, decision-making  
43 and peripheral visual perception in mentally fatigued football players <sup>10,7,5</sup>. We are not aware,  
44 however, of any experimental study investigating the effect of mental fatigue on repeated sprint  
45 ability (RSA). The ability to perform multiple sprints at high speed despite incomplete recovery  
46 is important in professional football <sup>8</sup>. Importantly, RSA is well known to induce metabolic  
47 perturbations within the muscle with concomitant reduction in cerebral deoxygenation <sup>11</sup>. The  
48 reduced brain oxygenation can impact areas such as the premotor cortex and motor cortex<sup>12</sup>  
49 which are relevant for cognitive tasks and descending motor commands. As previously  
50 observed, the reduced brain oxygenation is in part associated with reduced cognitive  
51 performance <sup>13</sup> and neural drive to the locomotor muscles (i.e., central fatigue) thus impairing  
52 physical performance <sup>11,14</sup>.

53 The first aim of our study was to investigate the effect of mental fatigue on RSA in  
54 professional football players. Although performance during physical tests that require short  
55 and maximal efforts does not seem to be negatively affected by mental fatigue <sup>15</sup>, we  
56 hypothesised that, due to multiple maximal efforts with incomplete recovery <sup>16</sup>, performance  
57 in the RSA test may be lower in mentally fatigued professional football players. The second  
58 aim of our study was to investigate the isolated and joint effects of physical and mental fatigue  
59 on psychomotor vigilance, operationally defined as the ability to quickly react to random visual  
60 stimuli and sustain attention over time <sup>17</sup>. A reduction in psychomotor vigilance is a clear sign  
61 of mental fatigue and high-intensity exercise has been shown to slow reaction time and reduce  
62 brain oxygenation in young and fit adults <sup>18,12,19</sup>. Third, as the left dorsolateral prefrontal cortex  
63 (L-DLPFC) is relevant for effortful cognitive tasks requiring inhibitory control and a wide  
64 range of tasks requiring psychomotor vigilance <sup>20</sup>, this study aimed to monitor the cerebral  
65 oxygenation of the L-DLPFC. Therefore, we hypothesised that both physical and mental  
66 fatigue reduce psychomotor vigilance in professional football players.

67

68

## Methods

69 ***Volunteers***

70 A group of 18 male professional football players were recruited from three different  
71 football teams: Gillingham FC, Cagliari Calcio S.p.a. and Team Ticino CH. Goalkeepers were  
72 excluded. One participant did not complete the experimental protocol due to personal reasons.  
73 The mean values  $\pm$  SD of height, weight and age for the remaining 17 participants were: 171.5  
74  $\pm$  5.2 cm, 75.5  $\pm$  1.8 kg, 26  $\pm$  2 years, respectively. None of the volunteers had any history of  
75 cardiorespiratory disease, were injured or taking any medication. All volunteers trained  
76 regularly at the time of the study (6-8 h/w) and were in the middle of the competitive season.  
77 Players signed an informed consent form describing the potentials risks and study procedures.  
78 Albeit not blind to treatment allocation, participants were not aware of that the main purpose  
79 of the study was to investigate the negative effects of mental fatigue on RSA and psychomotor  
80 vigilance. This “partial blinding” was implemented to reduce the nocebo effect on their  
81 performance. All the experimental procedures were approved by the local ethical committee  
82 and were conformed to the Declaration of Helsinki.

### 83 ***Experimental protocol***

84 This was a partially-blind, randomized crossover trial consisting of one preliminary  
85 session and two experimental sessions separated at least by 24 hours of recovery and completed  
86 within 14 days. Volunteers were asked to refrain from caffeine, alcohol, stimulants or  
87 depressants, and strenuous exercise for 24 hours prior to each experimental session. Volunteers  
88 performed each experimental session at the same time of the day at their training ground. The  
89 experimental protocol is illustrated in Fig 1.

90 The first visit served to familiarise volunteers with all the experimental procedures.  
91 Moreover, volunteers performed the Level 1 Yo-Yo intermittent recovery to assess their  
92 physical fitness.

93 During visits 2 and 3 each volunteer performed the RSA test in either an experimental  
94 (MF) or control (CON) condition according to a randomized and counterbalanced order. The  
95 RSA test consisted of 10 shuttle sprints of 40 m (20 + 20 m) at the maximal possible speed  
96 interspaced by 20 s of passive recovery. The RSA test was performed after 10 min of standard  
97 warm-up. Volunteers were instructed to sprint as fast as possible from the start and were  
98 verbally encouraged throughout each sprint to promote a maximal effort <sup>16</sup>. The main  
99 parameters obtained from the RSA test were RSA total time (RSA<sub>time</sub>), Running speed and  
100 decrement score (S<sub>dec</sub>). The person providing verbal encouragement during the RSA test was  
101 blind to treatment allocation.

### 102 ***Treatment***

103 The cognitive tasks were performed prior the RSA test in a quiet room under the  
104 supervision of the same researchers.

105 *Mental Fatigue Condition (MF) - demanding cognitive task:* mental fatigue was induced by  
106 using the paper version of the Stroop task for 30 min as in previous experiments <sup>9</sup>.

107 *Control Condition (CON) - non-demanding cognitive task:* the control treatment consisted of  
108 volunteers watching a documentary about the history of Ferrari for 30 min.

### 109 ***Psychological and physiological measures during the RSA test***

110 Global ratings of perceived exertion (RPE) were obtained during the recovery period  
111 between each sprint of the RSA test using the 15-point Borg RPE scale. Heart rate (HR) was  
112 continuously monitored during the RSA test by a HR monitor (Polar RS800CX, Polar Electro  
113 Oy, Kempele, Finland). A 20- $\mu$ l sample from the finger was taken at Baseline and after the

114 RSA test (Post-RSA) and analysed for blood lactate concentration ( $B[La^-]$ ) using a portable  
 115 analyser (Lactate Pro, Arkray Inc., Kyoto, Japan). Oxygenation of the left prefrontal cortex  
 116 (PFC) was measured via near infrared spectroscopy (NIRS) by means of a portable device  
 117 (Portalite, Artinis, Zetten, Netherlands) emitting continuous wavelengths of 760-850-nm. The  
 118 probe was placed on the left forehead Fp1/Fp3 according to the international  
 119 electroencephalographic 10-20 EEG system. Sampling frequency was set at 10 Hz. To obtain  
 120 baseline NIRS measures, data acquisition was performed for 4 min at rest with the volunteer  
 121 sitting on a chair in a relaxed position. The probe position was marked used anatomical  
 122 references for each volunteer to place it in the same position for each visit. Changes from  
 123 baseline concentration for oxyhaemoglobin ( $\Delta O_2Hb$ ), deoxyhaemoglobin ( $\Delta HHb$ ), total  
 124 haemoglobin ( $\Delta tHb = O_2Hb + HHb$ ) were calculated. An age-dependent differential optical  
 125 path length factor for cerebral cortex was used in the study. The same NIRS procedures were  
 126 used during both cognitive tasks.

### 127 *Other measures*

128 The Fatigue and Vigour subscales of the Brunel Mood Scale (BRUMS) were measured  
 129 at Baseline, after the cognitive tasks (Post-CT) and after the RSA test (Post-RSA) to quantify  
 130 subjective fatigue. The National Aeronautics and Space Administration Task Load Index  
 131 (NASA-TLX) was used to assess subjective workload at Post-CT and at Post-RSA. Motivation  
 132 related to the RSA test was measured beforehand using the Success Motivation and Intrinsic  
 133 Motivation scales of the Dundee Stress State Questionnaire.

134 The 3-min version of the PVT was performed at Baseline, Post-CT and Post-RSA.  
 135 Visual stimuli were provided by a red light appearing on the display screen of the device (PVT-  
 136 192, CWE, Inc, USA). Briefly, volunteers were asked to press the button as soon as the light  
 137 appeared. The light appeared randomly every few seconds for 3 min. The PVT has been shown  
 138 to be a valid and reliable tool for assessing psychomotor vigilance in various settings <sup>17</sup>. The  
 139 PVT was performed in the same room used for the cognitive tasks.

### 140 *Data analysis*

141 Brain oxygenation data were averaged over the last minute during baseline  
 142 measurement. During the cognitive tasks, the 30 min period was divided into 5 min blocks, and  
 143 data were averaged for the last minute for each block. During the RSA test, data were averaged  
 144 over the last 5 s for each sprint. Raw PVT data were inspected prior to analysis. Responses <  
 145 100 ms and above > 500 ms were excluded since the former is too fast to represent a conscious  
 146 response (false start response), and the latter were considered as lapses. Response speed was  
 147 calculated as the reciprocal of reaction time in milliseconds (RT) according to this formula:  
 148  $1/RT \times 1000$ . Fatigue index during the RSA test was calculated by using the sprint decrement  
 149 index ( $S_{dec}$ ) according to this formula:

$$150$$

$$151 \quad S_{dec} (\%) = \left\{ \frac{(S^1 + S^2 + S^3 + \dots S^{final})}{S^{best} \times \text{number of sprints}} - 1 \right\} \times 100$$

### 152 *Statistical analysis*

153 All data are presented as mean  $\pm$  SD unless otherwise noted. Assumption for normal  
 154 distribution was checked by using the Shapiro-Wilk test, whilst the assumption of sphericity  
 155 of data was checked by using the Mauchly's test. The Greenhouse-Geisser correction was  
 156 applied when violations to sphericity was found whilst a non-parametric alternative to the tests  
 157 listed below was used if the assumption of normality was not met. A two-way  $2 \times 10$  ANOVA  
 158 for repeated measures was performed to test the effect of condition (MF vs CON) and time

159 (defined as sprint number) on HR, RPE, running speed,  $\Delta O_2Hb$ ,  $\Delta Hb$ ,  $\Delta tHb$  during the RSA  
 160 test. A paired t-test was performed to test the effect of condition on B[La-] accumulation (Post-  
 161 RSA minus Baseline),  $RSA_{time}$  and  $S_{dec}$ .

162 A two-way  $2 \times 3$  ANOVA for repeated measures was performed to test the effect of  
 163 condition (MF vs CON) and time (Baseline, Post-CT, and Post RSA) on response speed during  
 164 the PVT, and for the Vigour and Fatigue scores. A paired t-test was performed to test the effect  
 165 of condition on  $RSA_{time}$  and  $S_{dec}$ , subjective motivation related to the RSA test, and on  
 166 subjective workload related to the cognitive tasks and RSA test. When a significant condition  
 167  $\times$  time interaction or a main effect of time were found, the relevant pairwise comparisons were  
 168 conducted using the Bonferroni method (post-hoc analysis). Alpha level was set at  $p < 0.05$ .  
 169 Statistical analysis was performed by SPSS [2627](#).

170

171

## Results

172 All volunteers completed the experiment without any adverse event. The average  
 173 distance covered on the Level 1 Yo-Yo test was  $2492 \pm 708$  m. This finding suggests that our  
 174 sample is representative of professional football players in terms of physical fitness <sup>21</sup>.

175 *Subjective measures.* The BRUMS questionnaire revealed a significant decrease in  
 176 Vigour over time in both conditions ( $p = 0.006$ ,  $\eta^2_p = 0.291$ ), with no significant condition  $\times$   
 177 time interaction ( $p = 0.277$ ,  $\eta^2_p = 0.082$ ). Post-hoc analysis revealed a significant lower Vigour  
 178 both at Post-CT ( $p = 0.017$ ,  $d\eta^2_p = 0.808081$ ) and Post-RSA ( $p = 0.027$ ,  $d\eta^2_p = 0.751212$ )  
 179 compared to Baseline in both conditions. The Fatigue subscale demonstrated a significant main  
 180 effect of time in both conditions ( $p = 0.001$ ,  $\eta^2_p = 0.582$ ) with no significant condition  $\times$  time  
 181 interaction ( $p = 0.573$ ,  $\eta^2_p = 0.028$ ). Post-hoc analysis revealed a significantly higher Fatigue  
 182 Post-RSA compared to Baseline and Post-CT ( $p = 0.006$ ,  $d\eta^2_p = 1.5701006$ ) (Table 1).

183 No significant differences between conditions were found for intrinsic motivation  
 184 (CON =  $18.57 \pm 4.99$ , MF =  $18.00 \pm 5.32$ ;  $p = 0.477$ ,  $d\eta^2_p = 0.1961823$ ) and motivation to  
 185 succeed in the RSA test (CON =  $17.07 \pm 5.40$ , MF =  $16.88 \pm 6.32$ ;  $p = 0.820$ ,  $d\eta^2_p =$   
 186  $0.0623445$ ) between the two conditions.

187 Concerning the subjective workload during the cognitive tasks, no significant  
 188 differences were found between MF and CON for Physical Demand ( $p = 0.100$ ,  $d\eta^2_p =$   
 189  $0.43813566$ ), Performance ( $p = 0.496$ ,  $d\eta^2_p = 0.17526861$ ) and Frustration ( $p = 0.138$ ,  $d\eta^2_p =$   
 190  $0.39134337$ ). On the contrary, Temporal Demand, Effort and Mental Demand were  
 191 significantly higher for the Stroop task compared to watching the documentary ( $p = 0.003$ ,  $d\eta^2_p =$   
 192  $0.87023343$ ,  $p = 0.044$ ,  $d\eta^2_p = 0.54831315$  and  $p = 0.007$ ,  $d\eta^2_p = 0.77829323$  respectively).  
 193 With regards to subjective workload during the RSA test, no significant differences between  
 194 conditions were reported for Physical Demand ( $p = 0.565$ ,  $d\eta^2_p = 0.15215337$ ), Performance  
 195 ( $p = 0.664$ ,  $d\eta^2_p = 0.11523289$ ), Effort ( $p = 0.738$ ,  $d\eta^2_p = 0.0881137$ ), Frustration ( $p = 0.276$ ,  
 196  $d\eta^2_p = 0.29319352$ ), Temporal Demand ( $p = 0.583$ ,  $d\eta^2_p = 0.15018985$ ) and Mental Demand  
 197 ( $p = 0.576$ ,  $d\eta^2_p = 0.14818014$ ) (Table 2).

198 *PVT.* A condition  $\times$  time interaction was found for response speed during the PVT ( $p =$   
 199  $0.001$ ,  $\eta^2_p = 0.399964$ ). Post-hoc analysis revealed no significant baseline difference between  
 200 conditions ( $p = 0.626352$ ,  $d_z = 0.129241$ ). At Post-CT the response speed significantly declined  
 201 compared to Baseline only in the MF condition ( $p = 0.007002$ ,  $d_z = 0.979608$ ) and was  
 202 significantly lower compared to CON ( $p = 0.001$ ,  $d_z = 1.0161073$ ). Post-RSA, the response  
 203 speed declined further in both conditions (CON  $p = 0.001$ ,  $d\eta^2_p = 1.3980748$ , MF  $p = 0.003$ ,  $d$

204 = 0.919) and remained lower in the MF condition compared to CON ( $p = 0.02312$ ,  $d_z =$   
205  $0.660722$ ) (Fig 2).

206 *RSA Test.*  $RSA_{\text{time}}$  and  $S_{\text{dec}}$  did not differ between conditions ( $p = 0.245$ ,  $d = 0.314$  and  
207  $p = 0.407$ ,  $d = 0.221$  respectively). RPE and HR significantly increased, while Running speed  
208 significantly decreased over time (all  $p < 0.001$  and all  $\eta^2_p > 0.681$ ) with no significant main  
209 effects of condition ( $p = 0.274$ ,  $\eta^2_p = 0.085$ ,  $p = 0.624$ ,  $\eta^2_p = 0.018$ , and  $p = 0.286$ ,  $\eta^2_p = 0.081$   
210 respectively) and no significant condition  $\times$  time interactions ( $p = 0.826$ ,  $\eta^2_p = 0.016$ ,  $p = 0.197$ ,  
211  $\eta^2_p = 0.106$ , and  $p = 0.128$ ,  $\eta^2_p = 0.115$  respectively). There was no significant difference  
212 between conditions in  $B[\text{La}^-]$  accumulation ( $p = 0.963$ ,  $d = 0.012$ ) (Fig 2).

213 *Brain oxygenation.*  $\Delta\text{O}_2\text{Hb}$  and  $\Delta\text{tHb}$  during the cognitive task were significantly  
214 higher in the MF condition compared to CON ( $p = 0.045$ ,  $\eta^2_p = 0.257$ ,  $p = 0.032$  and  $\eta^2_p = 0.287$   
215 respectively) while  $\Delta\text{HHb}$  was significantly lower in the MF condition compared to CON ( $p =$   
216  $0.031$ ,  $\eta^2_p = 0.290$ ) with no significant changes over time ( $p = 0.151$ ,  $\eta^2_p = 0.236$ ,  $p = 0.301$ ,  
217  $\eta^2_p = 0.081$  and  $p = 0.260$ ,  $\eta^2_p = 0.086$  respectively) and no significant time  $\times$  condition  
218 interaction ( $p = 0.668$  and  $\eta^2_p = 0.024$ , and  $p = 0.848$ ,  $\eta^2_p = 0.031$  respectively). During the  
219 RSA test,  $\Delta\text{O}_2\text{Hb}$  significantly decreased over time while  $\Delta\text{HHb}$ ,  $\Delta\text{tHb}$  increased over time (all  
220  $p < 0.001$  and all  $\eta^2_p > 0.305$ ) with no significant differences between conditions ( $p = 0.473$ ,  
221  $\eta^2_p = 0.048$ ,  $p = 0.780$ ,  $\eta^2_p = 0.007$  and  $p = 0.893$ ,  $\eta^2_p = 0.002$  respectively) and no significant  
222 condition  $\times$  time interaction ( $p = 0.889$ ,  $\eta^2_p = 0.041$ ,  $p = 0.780$ ,  $\eta^2_p = 0.048$  and  $p = 0.715$ ,  $\eta^2_p$   
223  $= 0.065$  respectively) (Fig 3).

224

## 225 Discussion

226 Contrary to our hypothesis, mental fatigue did not reduce RSA in professional football  
227 players. However, the results of this study suggest that mental fatigue and physical fatigue have  
228 negative and cumulative effects on psychomotor vigilance in this population.

### 229 *Effect of mental fatigue on psychomotor vigilance*

230 As expected, participants reported that the Stroop task was more effortful, and more  
231 mentally and temporally demanding than watching the documentary (control condition). In  
232 other words, the mental load associated with the Stroop task was higher than that of watching  
233 the documentary. The significant differences in brain oxygenation between the two tasks are  
234 in line with previous work<sup>17</sup> regarding the importance of the PFC activity for tasks like the  
235 Stroop that require inhibitory control. Despite no significant differences in the subjective  
236 measures of fatigue, a slower response speed during the PVT was found only after the Stroop  
237 task thus confirming the presence of mental fatigue and its negative effect of psychomotor  
238 vigilance<sup>17</sup>

### 239 *Effect of mental fatigue on repeated sprint ability*

240 RSA is important for professional football players and it is known to be affected by  
241 various factors such as energy supply, metabolite accumulation, reduced neural drive, and  
242 environmental factors<sup>8,11</sup>. One of the primary aims of the present study was to extend our  
243 understanding of the factors that affect RSA by testing the hypothesis that mental fatigue  
244 reduces it. However, we failed to find any significant effect of our experimental manipulation  
245 (30 min of a demanding and effortful cognitive task) on running speed during the subsequent  
246 RSA test. Additionally, mental fatigue did not affect brain oxygenation during the RSA test  
247 which may, in part explain, why RSA was not negatively affected by mental fatigue<sup>12</sup>.

248 Our findings align with those of Smith and colleagues who found no significant effect  
249 of mental fatigue on peak running velocities during a 45 min intermittent running protocol in  
250 a group of team sport players including footballers<sup>22</sup>. However, in the same study, Smith and  
251 colleagues found that mental fatigue increased perception of effort and reduced low-intensity  
252 running performance thus further demonstrating the negative effect of mental fatigue on  
253 aerobic endurance capacity in team sport players<sup>22</sup>. Although the ability to sprint seems to  
254 remain intact in mentally fatigued football players, their reduced aerobic endurance capacity  
255 may impair players' ability to move in the right field position when a sprint is required.

### 256 *Effect of physical fatigue and mental fatigue on psychomotor vigilance*

257 To the best of our knowledge, this is the first study investigating the effects of both  
258 mental fatigue and physical fatigue on psychomotor vigilance in professional football players.  
259 During the RSA test there was a substantial decrease in running speed as well as an increase in  
260 perception of effort which are both indicative of significant physical fatigue<sup>23</sup>. During repeated  
261 sprint exercise, the decrease in power production has been associated with PCr degradation and  
262 accumulation of various metabolites most probably derived from anaerobic glycolysis and by  
263 a progressive reduction in neural drive to the locomotor muscles (i.e., central fatigue)<sup>11</sup>. Our  
264 study also showed that oxygenation of L-DLPFC declined progressively during the RSA test  
265 in this group of professional football players. Similar findings have been reported during  
266 intermittent high intensity cycling exercise in a group of health and fit adults<sup>19</sup>. As previously  
267 suggested the progressive reduction in brain oxygenation may in part contribute to central  
268 fatigue during repeated sprints with insufficient recovery<sup>19,24</sup>.

269 Going back to the cognitive effects of physically fatiguing exercise, we found (in both  
270 conditions) a decline in response speed during the PVT performed after the RSA test. This  
271 novel finding is in line with the U-shape relationship between exercise intensity and cognitive  
272 performance, with low-to-moderate intensity exercise having a positive effect compared to  
273 resting conditions, whilst high-intensity exercise has a negative effect<sup>25</sup>. Given the important  
274 role played by the PFC in tasks like the Stroop that require inhibitory control<sup>26</sup>, it is possible  
275 that the reduced oxygenation of the PFC observed after the RSA test may contribute to the  
276 reduction in response speed during the PVT.

277 An even more important finding is the observation that response speed during the PVT  
278 was further reduced compared to baseline when players performed the RSA test in a mentally  
279 fatigued state. In other words, the negative effects of physical and mental fatigue on  
280 psychomotor vigilance are cumulative. Given that the ability to sustain attention and react  
281 quickly to visual stimuli is important in football and many other sports<sup>27</sup>, the cumulative effect  
282 of physical and mental fatigue on PVT performance observed in the present study is likely to  
283 be relevant to the technical and tactical performance of professional football players on the  
284 field and needs further investigations.

### 285 *Study limitations*

286 Our study has some technical limitations which should be considered when interpreting  
287 the results. In the "real world" context of official football matches, the physical and mental  
288 demands are likely to be significantly higher compared to those of this study. Congested  
289 fixtures, frequent travel and other psychological stressors associated with the life of a  
290 competitive footballer also contribute to physical and mental fatigue<sup>4</sup>. Therefore, both the  
291 physical and the mental fatigue experimentally induced in this study are likely to be less severe  
292 than those experienced by professional football players. Another limitation is that the PVT is  
293 not specifically designed for testing football players. Thus, the test might only partially capture  
294 the negative effects or indeed capture non relevant aspects of both physical and mental fatigue



295 on the psychomotor vigilance of professional football players. With regards to the NIRS  
296 measurements, the probe was placed only over the left PFC and therefore we cannot provide a  
297 full picture of brain oxygenation. For example, previous research has shown that prolonged  
298 cognitive tasks may also activate deeper cortical areas, such as the anterior cingulate cortex<sup>26</sup>,  
299 which ~~cannot~~ could not be monitored been accessed by NIRS. Furthermore, we did not include  
300 NIRS data during the PVT tests conducted immediately following the RSA test. Previous  
301 research has demonstrated a sudden hyperaemic response following high intensity exercise  
302 with high variability between participants<sup>28</sup>. Therefore, a reliable comparison of brain  
303 oxygenation across each PVT test was not possible. Lastly, our conclusions about the effects  
304 of physical fatigue are based on comparing measurements taken before, during and  
305 immediately after the fatiguing physical task (i.e., the RSA test). This study design is  
306 commonly used in studies about the ~~neuromuscular~~ neuromuscular effects of physical fatigue  
307<sup>23</sup>. Nevertheless, the inclusion of a resting control condition (which was not feasible in this  
308 occasion as it would have added one day of testing to the players burden) would have  
309 strengthened our conclusions about the negative effects of physical fatigue on psychomotor  
310 vigilance and brain oxygenation.

311

### Conclusion

312 Our study provides evidence that physical and mental fatigue have negative and  
313 cumulative effects on psychomotor vigilance in professional football players whilst there was  
314 no evidence to support the hypothesised negative effect of mental fatigue on RSA. Together  
315 with the findings of previous experimental studies on the effects of physical and mental fatigue  
316 on the physical, technical and cognitive performance of football players, it is clear that both  
317 kinds of fatigue can have a negative impact on football performance<sup>5,29</sup>.

318

319

### Practical applications

320 Given the evidence provided here that both mental and physical fatigue can reduce the  
321 psychomotor vigilance of professional football players, the practical recommendation is to  
322 implement strategies to reduce both types of fatigue. A strategy directly suggested by the  
323 present study is to reduce as much as possible the cognitively demanding tasks (e.g., tactical  
324 rehearsal and emotion control) before a soccer match. Our results also provide further  
325 justification for the use of caffeine before and during a match in professional football players  
326<sup>30</sup>. Indeed, caffeine is well known to improve physical performance and reduce the negative  
327 effects of mental fatigue in humans<sup>31</sup>. Further research is required to optimise the use of these  
328 strategies and develop new fatigue countermeasures for professional football players.

329

330

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334

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**References**

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1. Carling, C., Le Gall, F. & Dupont, G. Analysis of repeated high-intensity running performance in professional soccer. *J. Sports Sci.* **30**, 325–336 (2012).
2. Carling, C. Analysis of physical activity profiles when running with the ball in a professional soccer team. *J. Sports Sci.* **28**, 319–326 (2010).
3. Alberti, Iaia, M, Arcelli, E, Cavaggioni, L, & Rampinini, E. Goal scoring patterns in major European soccer leagues. *Sport Sci. Health* **9**, (2013).
4. Thompson, C. J. *et al.* Understanding the presence of mental fatigue in English academy soccer players. *J. Sports Sci.* **38**, 1524–1530 (2020).
5. Smith, M. R. *et al.* Mental Fatigue and Soccer: Current Knowledge and Future Directions. *Sports Med.* **48**, 1525–1532 (2018).
6. Smith, M. R. *et al.* Mental Fatigue Impairs Soccer-Specific Physical and Technical Performance. *Med. Sci. Sports Exerc.* **48**, 267–276 (2016).
7. Kunrath, C. A., Nakamura, F. Y., Roca, A., Tessitore, A. & Teoldo Da Costa, I. How does mental fatigue affect soccer performance during small-sided games? A cognitive, tactical and physical approach. *J. Sports Sci.* **38**, 1818–1828 (2020).
8. Rampinini, E. *et al.* Validity of Simple Field Tests as Indicators of Match-Related Physical Performance in Top-Level Professional Soccer Players. *Int. J. Sports Med.* **28**, 228–235 (2007).
9. Smith, M. R. *et al.* Mental Fatigue Impairs Soccer-Specific Physical and Technical Performance. *Med. Sci. Sports Exerc.* (2015) doi:10.1249/MSS.0000000000000762.
10. Habay, J. *et al.* Mental Fatigue and Sport-Specific Psychomotor Performance: A Systematic Review. *Sports Med. Auckl. NZ* **51**, 1527–1548 (2021).
11. Girard, O., Mendez-Villanueva, A. & Bishop, D. Repeated-sprint ability - part I: factors contributing to fatigue. *Sports Med. Auckl. NZ* **41**, 673–694 (2011).

- 364 12. Subudhi, A. W., Miramon, B. R., Granger, M. E. & Roach, R. C. Frontal and motor  
365 cortex oxygenation during maximal exercise in normoxia and hypoxia. *J. Appl. Physiol.*  
366 *Bethesda Md 1985* **106**, 1153–1158 (2009).
- 367 13. Li, Z. *et al.* Assessment of cerebral oxygenation during prolonged simulated driving  
368 using near infrared spectroscopy: its implications for fatigue development. *Eur. J. Appl.*  
369 *Physiol.* **107**, 281–287 (2009).
- 370 14. Spriet, L. L., Lindinger, M. I., McKelvie, R. S., Heigenhauser, G. J. & Jones, N. L.  
371 Muscle glycogenolysis and H<sup>+</sup> concentration during maximal intermittent cycling. *J.*  
372 *Appl. Physiol. Bethesda Md 1985* **66**, 8–13 (1989).
- 373 15. Van Cutsem, J. *et al.* Mental fatigue impairs visuomotor response time in badminton  
374 players and controls. *Psychol. Sport Exerc.* **45**, 101579 (2019).
- 375 16. Billaut, F., Bishop, D. J., Schaerz, S. & Noakes, T. D. Influence of knowledge of sprint  
376 number on pacing during repeated-sprint exercise. *Med. Sci. Sports Exerc.* **43**, 665–672  
377 (2011).
- 378 17. Basner, M. & Dinges, D. F. Maximizing sensitivity of the psychomotor vigilance test  
379 (PVT) to sleep loss. *Sleep* **34**, 581–591 (2011).
- 380 18. Ando, S. Peripheral visual perception during exercise: why we cannot see. *Exerc. Sport*  
381 *Sci. Rev.* **41**, 87–92 (2013).
- 382 19. Smith, K. J. & Billaut, F. Influence of cerebral and muscle oxygenation on repeated-  
383 sprint ability. *Eur. J. Appl. Physiol.* **109**, 989–999 (2010).
- 384 20. Diamond, A. Executive Functions. *Annu. Rev. Psychol.* **64**, 135–168 (2013).
- 385 21. Bangsbo, J., Iaia, F. M. & Krstrup, P. The Yo-Yo intermittent recovery test : a useful  
386 tool for evaluation of physical performance in intermittent sports. *Sports Med. Auckl. NZ*  
387 **38**, 37–51 (2008).

- 388 22. Smith, M. R., Marcora, S. M. & Coutts, A. J. Mental Fatigue Impairs Intermittent  
389 Running Performance. *Med. Sci. Sports Exerc.* **47**, 1682–1690 (2015).
- 390 23. Enoka, R. M. & Stuart, D. G. Neurobiology of muscle fatigue. *J. Appl. Physiol. Bethesda*  
391 *1985* **72**, 1631–1648 (1992).
- 392 24. Nybo, L. & Rasmussen, P. Inadequate cerebral oxygen delivery and central fatigue  
393 during strenuous exercise. *Exerc. Sport Sci. Rev.* **35**, 110–118 (2007).
- 394 25. Tomporowski, P. D. Effects of acute bouts of exercise on cognition. *Acta Psychol.*  
395 *(Amst.)* **112**, 297–324 (2003).
- 396 26. Carter, C. S. *et al.* Anterior cingulate cortex, error detection, and the online monitoring of  
397 performance. *Science* **280**, 747–749 (1998).
- 398 27. Memmert, D. Pay attention! A review of visual attentional expertise in sport. *Int. Rev.*  
399 *Sport Exerc. Psychol.* **2**, 119–138 (2009).
- 400 28. Jones, B., Hesford, C. M. & Cooper, C. E. The use of portable NIRS to measure muscle  
401 oxygenation and haemodynamics during a repeated sprint running test. *Adv. Exp. Med.*  
402 *Biol.* **789**, 185–191 (2013).
- 403 29. Bangsbo, J., Mohr, M. & Krstrup, P. Physical and metabolic demands of training and  
404 match-play in the elite football player. *J. Sports Sci.* **24**, 665–674 (2006).
- 405 30. Tallis, J. *et al.* The prevalence and practices of caffeine use as an ergogenic aid in English  
406 professional soccer. *Biol. Sport* **38**, 525–534 (2021).
- 407 31. Lorist, M. M. & Tops, M. Caffeine, fatigue, and cognition. *Brain Cogn.* **53**, 82–94  
408 (2003).

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### Figure captions

**Fig 1. Overall view of the experimental protocol.**

Brain oxygenation was measured during the cognitive tasks and the repeated sprint ability (RSA) test. Additionally, during the RSA test, rating of perceived exertion and heart rate were measured. PVT stands for psychomotor vigilance task.

**Fig 2. Physiological and perceptual responses during the repeated sprint ability (RSA) test and psychomotor vigilance (PVT) test.**

Panel A shows time courses of running speed; Panel B shows time courses of heart rate (HR); Panel C shows time courses of rating of perceived exertion (RPE); Panel D shows the effect of cognitive tasks and RSA test on response speed during the PVT at baseline, after the cognitive tasks (Post-CT) and after RSA test (Post-RSA). Panel E shows blood lactate (B[La-]) accumulation. #Denotes significant condition x time interaction. \*Denotes significant main effect of time. †Significantly different from CON condition. Data are presented as mean  $\pm$  SD (n=17).

**Fig 3. Brain oxygenation changes from resting baseline (BL) during the cognitive tasks and the repeated sprint ability (RSA) test.**

Panel A, B and C show time courses of oxyhaemoglobin ( $\Delta O_2Hb$ ), deoxyhaemoglobin ( $\Delta HHb$ ) and total haemoglobin ( $\Delta tHb$ ) during the cognitive tasks. Panel D, E and F show time courses  $\Delta O_2Hb$ ,  $\Delta HHb$  and  $\Delta tHb$  during the repeated sprint ability (RSA) test. \*Denotes significant main effect of time. †Denotes significant main effect of condition. Data are presented as mean  $\pm$  SD (n=17).

**Table 1. Subjective ratings of vigour and fatigue.**

	Vigour		Fatigue	
	CON	MF	CON	MF
<b>Baseline</b>	8.88-9 ± 3.04	8.50 ± 3.03	4.75 ± 2.869	5.56-6 ± 2.94
<b>Post-CT</b>	6.69-7 ± 3.63*	7.13 ± 3.677*	5.81 ± 3.667*	7.13-2 ± 4.263*
<b>Post-RSA</b>	6.75 ± 2.82*	5.81 ± 3.51*	9.38-4 ± 3.34*	9.75 ± 3.21*

Subjective ratings of Vigour and Fatigue in mental fatigue (MF) and control (CON) condition measured through the Brunel Mood Scale (BRUMS) questionnaire. Values are expressed as mean ± SD. \*Significantly different compared to Baseline.

**Table 2. Subjective ratings of workload.**

	Mental Demand		Physical Demand		Temporal Demand		Performance		Effort		Frustration	
	CON	MF	CON	MF	CON	MF	CON	MF	CON	MF	CON	MF
<b>Cognitive task</b>	42.19 2 ± 23.94	65.00 ± 23.24*	0.63 ± 2.50	6.56 ± 13.00	30.31 ± 20.374	50.63 ± 18.43*	50.31 ± 22.32	55.00 ± 21.76	25.31 ± 22.40	46.88-9 ± 31.465*	24.38 ± 22.94	37.81 ± 36.384
<b>RSA test</b>	72.67 7 ± 15.576	70.94 ± 16.55	88.67 7 ± 14.60	85.00 ± 16.43	61.43 ± 16.42	60.63 ± 20.40	65.33 ± 19.50	67.50 ± 19.83	85.67 7 ± 13.485	86.88-9 ± 16.92	54.00 ± 30.31	61.56 ± 30.54

Subjective ratings of Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration in mental fatigue (MF) and control (CON) condition assessed through the National Aeronautics and Space Administration Task Load Index (NASA-TLX) questionnaire. Values are expressed as mean ± SD. \*Significantly different compared to CON.

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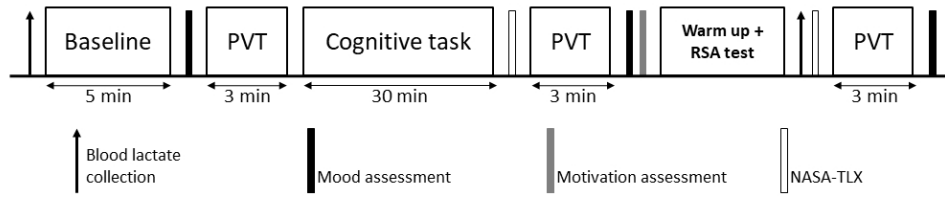


Figure 1

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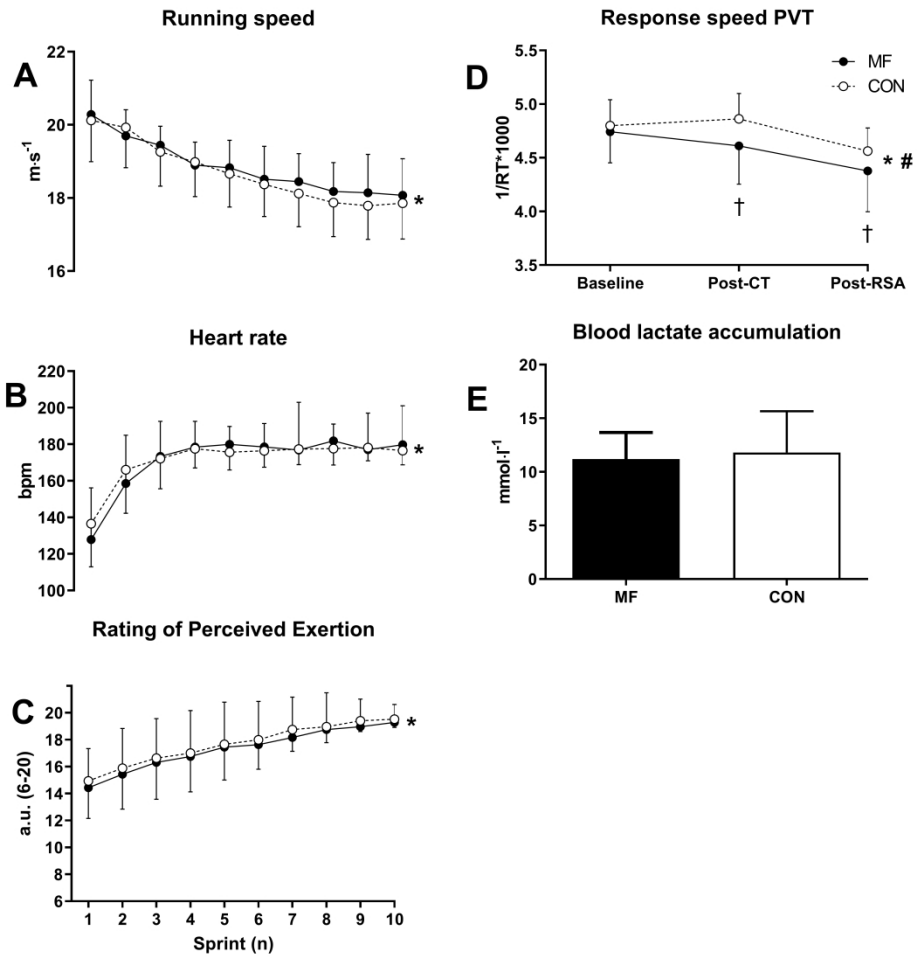


Figure 2

208x210mm (600 x 600 DPI)



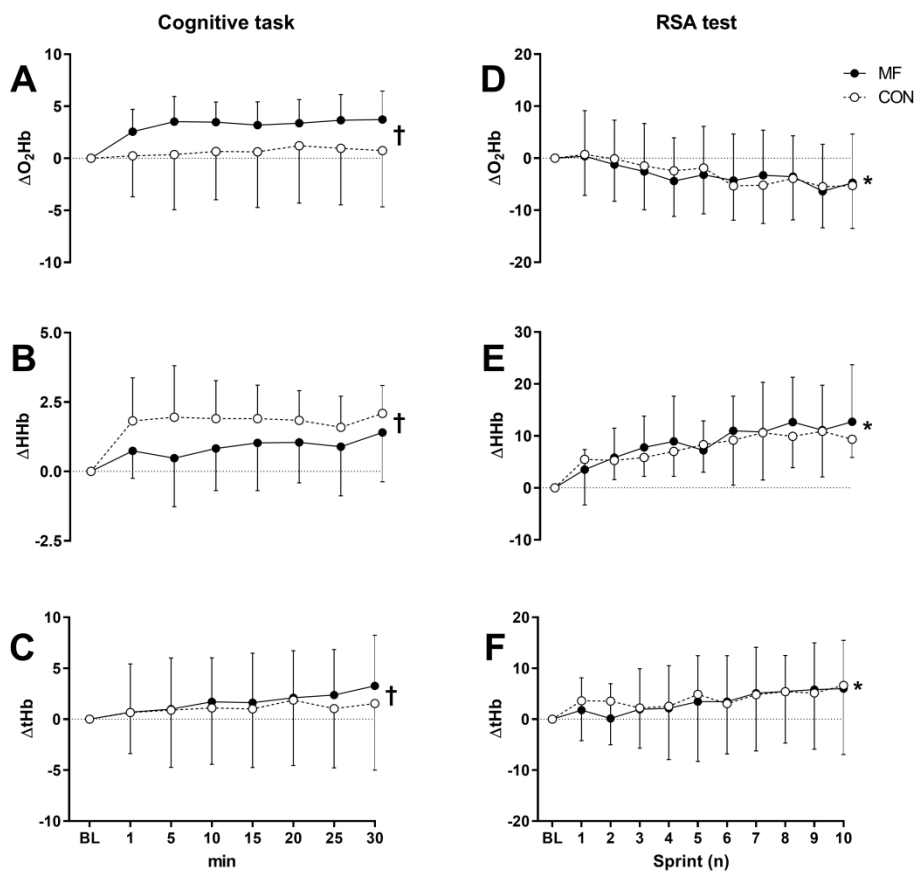


Figure 3

190x176mm (600 x 600 DPI)