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Brain Endurance Training Improves Physical, Cognitive, and Multitasking Performance in Professional Football Players

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35 **Abstract**

36

37 **Purpose:** Brain endurance training (BET)—the combination of physical training with
38 mentally fatiguing tasks—could help athletes adapt and increase their performance during
39 sporting competitions. Here we tested whether BET completed after standard physical
40 training improved physical and mental performance more than physical training alone during
41 a preseason football training camp. **Methods:** The study employed a pretest/training/posttest
42 design, with 22 professional football players randomly assigned to BET or a control group.
43 Both groups completed 40 physical training sessions over 4 weeks. At the end of a day of
44 physical training, the BET group completed cognitive training, whereas the control group
45 listened to neutral sounds. Players completed the 30–15 Intermittent Fitness Test, repeated
46 sprint ability random test, soccer-specific reactive agility test, and Stroop and psychomotor
47 vigilance tests pretraining and posttraining. Mixed analysis of variance was used to analyze
48 the data. **Results:** In the posttest (but not pretest) assessments, the BET group consistently
49 outperformed the control group. Specifically, the BET group was faster ($P = .02-.04$) than the
50 control group during the 30–15 Intermittent Fitness Test, the directional phase of the repeated
51 sprint ability random test, and the soccer-specific reactive agility test. The BET group also
52 made fewer errors ($P = .02$) during the soccer-specific reactive agility test than the control
53 group. Finally, the BET group responded faster ($P = .02$) on the Stroop test and made fewer
54 ($P = .03$) lapses on the psychomotor vigilance test than the control group. **Conclusion:** The
55 inclusion of BET during the preseason seems more effective than standard physical training
56 alone in improving the physical, cognitive, and multitasking performance of professional
57 football players.

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59

60 **Keywords:** cognitive training, mental fatigue, elite athletes, sport performance, team sport,
61 neuro-performance

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66 Introduction

67
68 Mental fatigue has been defined as a psychobiological state induced by prolonged periods
69 of demanding cognitive activity, which is characterized by feelings of tiredness and lack of
70 energy.^{1,2} Football players are required to react to various stimuli, make quick decisions,
71 remember and switch strategies, and stay alert during the whole match. As a result, they can
72 develop mental fatigue over time.³ Stressors other than playing football (eg, travel and
73 education) can also induce mental fatigue.⁴ With regards to performance, this is not optimal
74 because research studies have demonstrated that mental fatigue can impair aerobic capacity,⁵
75 intermittent running velocity,⁶ decision making,^{5,6} technical skills,^{5,7} and psychomotor
76 vigilance.⁸ Therefore, it is necessary to develop strategies to reduce the negative effects of
77 mental fatigue in football players.

78 Given evidence that physical and mental effort involve several overlapping brain regions,⁹
79 Marcora et al.¹⁰ proposed an innovative training method—brain endurance training (BET)—
80 to increase the cognitive load of physical training to make athletes more resilient to mental
81 fatigue and improve their endurance performance. Their seminal study showed that the
82 addition of a 60-minute cognitive task to a standard physical training program focusing on
83 endurance (ie, a 60-min cycling task performed 3 times per week for 12 wk) led to greater
84 improvements in endurance measured with a cycling time to exhaustion test. The improved
85 endurance performance with BET was explained in terms of brain adaptations to the
86 systematic cognitive overload resulting in a reduction in the perception of effort during the
87 cycling to exhaustion test. The benefit of *concurrent* BET for endurance performance has
88 since been replicated by another research group using a rhythmic handgrip exercise task.¹¹
89 Taken together, these studies argue for a beneficial effect of BET on endurance performance
90 when the cognitive task is performed *during* exercise. However, adding a concurrent
91 cognitive task may not always be practical during football training on the field. Therefore,
92 other combinations of cognitive training and physical training should be investigated. For
93 example, the coach could ask the players to perform a demanding cognitive task before the
94 physical training session (*pre* BET) so that they train in a state of mental fatigue. Another
95 possibility is to perform a demanding cognitive task during the recovery periods of a high-
96 intensity interval training session (*intermixed* BET) so that, while the body recovers between
97 the exercise bouts, the brain remains highly engaged. Finally, it is possible to add the
98 demanding cognitive task immediately after the session when the players are fatigued by the
99 physical training (*post* BET). Potentially, all of these combinations could induce positive
100 brain adaptations and increase the overall training load imposed on the players without
101 increasing the physical load. In injured athletes or athletes at high risk of overuse injuries,
102 coaches could also use BET to maintain the overall training load when the physical load is
103 reduced. Given these potential practical applications, further experimental research on the
104 effects of BET is warranted. Such research should also include other outcomes in addition to
105 endurance performance. Indeed, because of its multitasking nature, BET may also help to
106 improve performance when physical and cognitive tasks have to be performed
107 simultaneously (dual tasking) or in rapid succession (task switching), which would obviously
108 be highly beneficial in football players and other team sports in which optimal multitasking
109 performance is required.

110 The aim of the present investigation was to evaluate the effects of *post* BET during the
111 preseason stage of professional footballers' training. To the best of our knowledge, this is the
112 first study to investigate the effects of BET in football players. We hypothesized that *post*
113 BET would enhance physical and cognitive performance in both single and multitasking
114 conditions compared with standard physical training alone.

115

116 **Methods**

117

118 *Participants*

119 A convenience sample of 25 male professional football players from a team in the Italian
120 third division (mean [SD], age 22.4 [4.3] y, height 175.4 [6.2] cm, weight 72.8 [6.6] kg) were
121 recruited. They signed an informed consent form to participate in this study, which was
122 approved by the ethics committee for the Region of Southern Denmark in accordance with
123 the standards of the Declaration of Helsinki. Players with injuries or bespoke training plans
124 were excluded from the study. During the study, 3 participants (one from the BET group and
125 2 from the control group) dropped out due to injuries; therefore, the analyses were performed
126 on an effective sample of 22 players. All players received written instructions describing the
127 study protocol but were naïve to its aims and hypotheses. Post hoc power calculations using
128 G*Power indicated that, with a sample size of 22, our study was powered at 80% to detect
129 significant ($P < .05$) between-within interaction effects ($f = 0.31$, $\eta^2p = .09$) corresponding
130 to a small to medium effect size by analysis of variance.

131

132 *Experimental Design*

133 The study employed a stratified randomized, pretest/posttest, controlled design. After
134 baseline testing (pretest), participants were stratified according to playing position
135 (goalkeepers, defenders, midfielders, and forwards) and randomly assigned to a BET group (n
136 = 13) or control group ($n = 12$). Participants were tested again after 4 weeks of training
137 (posttest).

138

139 *Testing*

140 Players performed physical and cognitive tests over 7 testing sessions: 1 familiarization
141 session, 3 pretest sessions, and 3 posttest sessions. All testing sessions were conducted on the
142 same football pitch and at the same time of day during the preseason (July– August). Tests
143 were completed in the week before and the week after the 4-week training period. Prior to
144 each testing session, players followed a standardized routine regarding sleep, recovery,
145 meals, hydration, supplementation, and medication. Temperature and humidity were
146 monitored, and testing sessions rescheduled if environmental conditions were unusual. At the
147 start of each testing session, players completed a motivation questionnaire (see
148 “Psychological Measures” section) and a standardized physical warm-up. During group
149 testing sessions, players verbally encouraged each other, but no verbal encouragement was
150 provided by the experimenter in any of the testing sessions. During testing session 1, players
151 completed the battery of physical and cognitive tests and questionnaires to familiarize them
152 with the assessments.

153 During testing session 2, players performed the 30 to 15 intermittent fitness test (IFT),¹²
154 an incremental running test designed to measure endurance in team sport athletes. The
155 velocity in kilometers per hour of the final and fully completed stage was recorded as the
156 velocity IFT. This test has been shown to have good test–retest reliability with a typical error
157 of measurement to be of 0.3 km/h (intraclass correlation coefficient = .96). Heart rate (HR)
158 and a capillary blood sample were obtained upon task completion. Players rested for 30
159 minutes before completing a 30-minute incongruent Stroop color-word test¹³ on a personal
160 computer. Reaction time (in milliseconds) and accuracy (in percentage of correct answers)
161 were computed. Finally, players completed a NASA task load index (NASA-TLX)¹⁴ to assess
162 the demands of the Stroop test.

163 During testing session 3, players performed the soccer-specific reactive agility test (S-
164 RAG)¹⁵ using a Fit Light Trainer system (Fitlight Corp). This test measures ability to sprint,
165 agility, change direction, and visuomotor response and have good test–retest reliability

166 (intraclass correlation coefficient = .88 for reactive agility time). We adapted the original test
167 by asking players to sprint continuously and complete the circuit without rests. Their goal
168 was to run toward the illuminated light, touch it with their contralateral hand, and return to
169 base. They completed 3 sets of 10 lights, with a 20-second recovery between sets. The lights
170 were illuminated in a counterbalanced pseudorandom order. This version of the task was
171 designed to increase mental fatigue (eg, by requiring participants to inhibit the natural
172 isomorphic response to respond by touching the light with their closest hand). This feature
173 also simulated a match situation where a defending player blocks an attacker with the
174 opposite side compared with the direction. Performance was measured as time (in seconds) to
175 complete the task and response accuracy (in percentage errors). A capillary blood sample was
176 obtained upon task completion.

177 During testing session 4, players performed the repeated sprint ability random test
178 (RSA).¹⁶ This test measures acceleration, change of direction, visuomotor response, and
179 decision making. Test–retest reliability for the mean time variable is high with an intraclass
180 correlation coefficient between .88 and .90. The test comprised 12 × 20-m sprints, with each
181 sprint followed by 20 seconds of active recovery while jogging back 20 m to the starting
182 position. Each sprint comprised a 10-m linear sprint plus a 10-m directional sprint to 1 of 3
183 randomly cued locations. The location of each directional sprint was cued by the illumination
184 of 1 of 3 colored lights after completing the previous 10-m linear sprint. Performance was
185 measured as the average time taken to complete the 10-m linear sprint (time [in seconds]) and
186 10-m directional sprint (time [in seconds]). Participants also completed a 10-minute
187 psychomotor vigilance test¹⁷ 30 minutes before and 30 minutes after the sprint test. Reaction
188 time (in milliseconds), for responses between 100 and 500 milliseconds, and number of
189 lapses, defined as responses slower than 500 milliseconds, were computed. We aimed to
190 compare the effect of BET training on PVT player’s performance in a fresh state (before the
191 RSA) and in a fatigued state (after the RSA).

192

193 *Training interventions*

194 All players completed 40 physical training sessions over a 4-week period under the
195 supervision of the club’s physical trainer. They trained once or twice per day, 5 days per
196 week. They were instructed to follow the prescribed physical training program without
197 completing any extra physical training session in order to standardize the impact of physical
198 training on posttest performance. Intensity, frequency, load, and type of training were
199 monitored by the physical trainer and coach. Weekly training load was measured using the
200 number of minutes training in the 5 HR zones.¹⁸ NASA-TLX¹⁴ was used to measure various
201 aspects of the perceived workload of each training session and averaged over each week
202 before analysis.

203 The BET group was asked to complete, 4 to 5 times a week, a cognitive task for 20 to 30
204 minutes immediately following the last daily physical training session, for a total of 400
205 minutes over the 4-week period. If there were 2 training sessions in the same day, players
206 performed the cognitive tasks after the second session. The duration of the cognitive task
207 used for *post* BET session was constrained by the players’ high daily volume of physical
208 training. However, Giboin and Wolff¹⁹ demonstrated that mental fatigue and its acute
209 detrimental effects on physical performance are dependent not only on the duration but also
210 on the demands of the cognitive task. In other words, high demand cognitive activity for a
211 short period or low-demand cognitive activity for a prolonged period can similarly increase
212 mental fatigue. In the current study, players performed 1 of 3 highly demanding cognitive
213 tasks—flanker task, go/no-go task, AX-continuous performance test using the SOMA-NPT
214 app (Sswitch.ch) running on a tablet computer. All 3 tasks include response inhibition that
215 induce mental fatigue.²⁰ Participants were instructed to choose to complete 1 of the 3

216 cognitive tasks on each session while ensuring balance between the 3 cognitive tasks across
217 the 4 weeks of training. To reduce placebo effect, participants were told that these tasks were
218 used to assess their cognitive performance throughout the preseason rather than being a new
219 mode of training.

220 The control group listened to 3 emotionally neutral sounds in a random order for 20 to 30
221 minutes following the last daily physical training session for 4 to 5 sessions per week for a
222 total of 400 minutes over the 4-week period. They were told the sounds were designed to
223 induce relaxation. However, the emotional valence of these specific sounds was neutral to
224 avoid any positive or negative psychological effect.²¹ This control treatment was chosen to
225 reduce threats to internal validity, like resentful demoralization and compensatory rivalry, in
226 the players not randomly allocated to *post* BET.

227

228 *Physiological Measures*

229 The HR was measured using a telemetric sensor (Polar S610i, Polar Electro Oy) during
230 each physical training session and upon completion of the 30–15 IFT. Blood lactate
231 concentration (in millimoles per liter) was measured by taking a 5- μ L sample of whole fresh
232 capillary blood from the right middle finger and analyzed using a portable analyzer (Lactate
233 Pro LT-1710, Arkray) upon completion of the 30–15 IFT and the reactive agility test.

234

235 *Psychological Measures*

236 Motivation was measured by asking players to rate the statement “I am motivated to
237 perform the test” using a 5-point Likert scale, with anchors of 0 (not at all) and 4 (extremely).
238 Perceived workload was measured using the mental demand, physical demand, and effort
239 subscales of the NASA-TLX¹⁴ upon completion of each training session and after the Stroop
240 test.

241

242 *Statistical analysis*

243 All data are presented as mean (SD) unless otherwise stated. A series of mixed group
244 (BET and control) by time (pretest and posttest) analyses of variances (ANOVAs) were
245 performed on the variables measured during the testing sessions. A series of mixed group
246 (BET and control) \times week (1, 2, 3, and 4) ANOVAs were performed on the training
247 variables. Significant group \times time interactions were followed up with unpaired *t* tests for the
248 simple main effects of group. Significance was set at .05 (2-tailed) for all analyses. The effect
249 sizes for the ANOVAs were calculated as partial eta squared (η^2_p), with .02, .13, and .26
250 indicating small, medium, and large effects, respectively. Data analysis was conducted using
251 the Statistical Package for Social Science (version 27).

252

253

254 **Results**

255

256 *Training Variables*

257 All players completed 40 physical training sessions, including occasional daily double
258 sessions and friendly practice matches, during the 4-week training period. Group \times week
259 ANOVAs on the total number of minutes across the 5 HR zones found effects of week but no
260 group or group \times week effects (Table 1). Group \times week ANOVAs on the NASA-TLX
261 variables found an effect of group on mental demand and effects of time on all of the 3
262 subscales. No other group effects or group \times week effects were found on the NASA-TLX
263 variables. All players in the BET group complied with the prescribed 400 minutes of
264 cognitive tasks spread among 18 (2) training sessions. Similarly, the control group listened to
265 400 minutes of neutral sounds spread among 19 (1) training sessions.

266 *Motivation*

267 No group ($F_{1,20} = 0.09$, $P = .77$, $\eta^2_p = .01$) time ($F_{1,20} = 2.62$, $P = .13$, $\eta^2_p = .14$), or
268 group \times time ($F_{1,20} = 0.22$, $P = .64$, $\eta^2_p = .01$) effects were found for motivation. These data
269 confirmed that the BET and control groups were similarly motivated throughout the pretest
270 and posttest assessments (grand mean: 3.1 [0.9]).

271

272 *Physical Performance*

273 The ANOVA yielded a group \times time interaction for velocity at the end of the 30–15 IFT
274 ($F_{1,20} = 5.12$, $P = .04$, $\eta^2_p = .09$; Figure 1A). Follow-up tests revealed that the BET group
275 was faster than the control group at posttest ($P = .04$). No main effect of time was found for
276 velocity ($F_{1,20} = 2.09$, $P = .14$, $\eta^2_p = .05$). No group ($F_{1,20} = 0.85$, $P = .37$, $\eta^2_p = .04$), time
277 ($F_{1,20} = 1.68$, $P = .21$, $\eta^2_p = .08$), or group \times time ($F_{1,20} = 1.83$, $P = .19$, $\eta^2_p = .08$) effects
278 were found for blood lactate concentration (BET pre: 10.1 [1.5], BET post: 9.6 [2]; control
279 pre: 10.5 [1.8], control post: 9.7 [1.9]). Similarly, HR at the end of the fitness test (BET pre:
280 194 [10], BET post 192 [8]; control pre: 196 [9], control post: 191 [11]) did not show any
281 effects for group ($F_{1,20} = 0.30$, $P = .59$, $\eta^2_p = .02$), time ($F_{1,20} = 2.90$, $P = .10$, $\eta^2_p = .13$),
282 or group \times time ($F_{1,20} = 2.56$, $P = .13$, $\eta^2_p = .11$).

283

284 *Cognitive Performance*

285 In the Stroop test, there was a group \times time interaction for reaction time ($F_{1,20} = 6.26$, $P =$
286 $.02$, $\eta^2_p = .13$; Figure 2A). Reaction times decreased from pretest to posttest in both groups
287 ($F_{1,20} = 6.38$, $P = .02$, $\eta^2_p = .26$), and, importantly, the BET group was faster than control
288 at posttest ($P < .001$). Accuracy did not vary as a function of group ($F_{1,20} = 0.13$, $P = .91$,
289 $\eta^2_p = .00$), time ($F_{1,20} = 0.31$, $P = .58$, $\eta^2_p = .02$), and group \times time ($F_{1,20} = 0.12$, $P = .73$,
290 $\eta^2_p = .01$). Accuracy was universally high (grand mean: 94% [2%] correct responses). The
291 NASA-TLX subscales completed after the Stroop test revealed group \times time interactions for
292 mental demand ($F_{1,20} = 16.61$, $P < .001$, $\eta^2_p = .17$) and effort ($F_{1,20} = 17.55$, $P < .001$, η^2_p
293 $= .24$). Follow-up tests revealed that at posttest, the Stroop test was less ($P_s = .02$ – $.03$)
294 demanding for BET (39 [6]) than control (71 [7]) and effortful for BET (48 [4]) than control
295 (69 [5]). No main effects of time were noted for mental demand ($F_{1,20} = 0.40$, $P = .54$, $\eta^2_p =$
296 $.02$) and effort ($F_{1,20} = 0.01$, $P = .92$, $\eta^2_p = .00$). No effects emerged for physical demand
297 (group [$F_{1,20} = 0.50$, $P = 0.53$, $\eta^2_{pp} = .03$], time [$F_{1,20} = 1.84$, $P = 0.21$, $\eta^2_{pp} = .08$], and
298 group by time [$F_{1,20} = 0.39$, $P = .62$, $\eta^2_p = .03$], grand mean 15 [9]). No significant effects
299 were found for lapses when players performed the PVT before the RSA (fresh state; group
300 [$F_{1,20} = 0.78$, $P = .55$, $\eta^2_p = .02$], test [$F_{1,20} = 0.99$, $P = .30$, $\eta^2_p = .02$], and group \times time
301 [$F_{1,20} = 0.47$, $P = .46$, $\eta^2_p = .01$]; grand mean 1.8 [0.3] lapses; Figure 2B). However, in the
302 PVT performed after the RSA (fatigued state), there was a significant group \times time
303 interaction for number of lapses ($F_{1,20} = 5.38$, $P = .03$, $\eta^2_p = .14$; Figure 2B). Follow-up
304 tests revealed that, compared with the control group, the number of lapses in the fatigued
305 state was significantly lower in the posttest in the BET group ($P = .01$). No main effect of
306 time was found for lapses ($F_{1,20} = 1.89$, $P = .17$, $\eta^2_p = .04$). No significant effects emerged
307 for reaction time in either the fresh state (group [$F_{1,20} = 0.49$, $P = .49$, $\eta^2_p = .02$], time [$F_{1,20}$
308 $= 1.94$, $P = .18$, $\eta^2_p = .09$], and group \times time [$F_{1,20} = 0.43$, $P = .52$, $\eta^2_p = .02$]; grand mean
309 331 [22] ms) or in the fatigued state (group [$F_{1,20} = 0.78$, $P = .40$, $\eta^2_p = .04$], time [$F_{1,20} =$
310 1.14 , $P = .28$, $\eta^2_p = .04$], and group \times time [$F_{1,20} = 0.27$, $P = .66$, $\eta^2_p = .02$]; grand mean
311 315 [25] ms).

312

313 *Multi-tasking performance*

314 The ANOVA uncovered a group \times time interaction effect for the directional sprints in the
315 RSA ($F_{1,20} = 4.66$, $P = .04$, $\eta^2_p = .05$; Figure 1B): Follow-up tests revealed that the BET

316 group was faster than the control group ($P = .04$) at posttest. No main effect of time was
317 found ($F_{1,20} = 3.09$, $P = .09$, $\eta^2_p = .08$). Analysis of the linear acceleration phase of the RSA
318 revealed neither main effect of group ($F_{1,20} = 1.33$, $P = .26$, $\eta^2_p = .06$) nor main effect of
319 time ($F_{1,20} = 2.10$, $P = .16$, $\eta^2_p = .06$), and no interaction ($F_{1,20} = 0.07$, $P = .80$, $\eta^2_p = .00$)
320 (grand mean: 2.3 [0.2]). The ANOVA found a group \times time interaction on time to complete
321 the S-RAG test ($F_{1,20} = 5.41$, $P = .03$, $\eta^2_{pp} = .11$; Figure 3A), with both groups faster at
322 posttest than pretest ($F_{1,20} = 7.70$, $P = .01$, $\eta^2_p = .10$) and the BET group faster than control
323 at posttest ($P = .04$). A group \times time interaction for hand errors ($F_{1,20} = 6.36$, $P = .02$, $\eta^2_p =$
324 $.18$; Figure 3B) revealed that although both groups erred less at posttest than pretest ($F_{1,20} =$
325 4.66 , $P = .04$, $\eta^2_p = .10$), the BET group made fewer mistakes than control at posttest ($P =$
326 $.03$). Blood lactate concentration at completion of S-RAG (BET pre: 11.4 [1.8], BET post:
327 12.1 [2.1]; control pre: 11.9 [2.4], control post: 12.2 [2.5]) did not show any group ($F_{1,20} =$
328 1.67 , $P = .21$, $\eta^2_p = .07$), time ($F_{1,20} = 2.60$, $P = .11$, $\eta^2_p = .08$), or group \times time ($F_{1,20} =$
329 0.85 , $P = .37$, $\eta^2_p = .04$) effects.

330

331

332 Discussion

333

334 The aim of the present study was to investigate the effects of a 4-week BET intervention
335 on physical, cognitive, and multitasking performance in professional football players.
336 Specifically, we added 20- to 30-minute demanding cognitive tasks after some of the physical
337 training sessions (*post* BET). This experimental manipulation increased on average across the
338 weeks by 28% the perceived mental demand of training compared with the control group that
339 performed the same physical training program without the added cognitive tasks. This finding
340 is in line with the results of previous studies of *concurrent* BET^{10,11} and suggests that *post*
341 BET is another effective strategy to increase the cognitive load of physical training.
342 Importantly for the interpretation of the following results is the fact that the physical load
343 experienced by the BET and control groups was not significantly different as indicated by
344 both the perceived physical demand ratings and the analysis of HR during training.
345 Therefore, any difference in the outcomes of training is most likely due to the additional
346 cognitive load provided by *post* BET rather than differences in physical load. It is worth
347 noting that this difference in cognitive load was achieved using relatively short (ie, 20–30
348 min) cognitive tasks, which were well tolerated by the players and did not affect the quantity
349 and quality of their physical training.

350

351 *BET and Physical Performance*

352 The changes in 30–15 IFT indicated that endurance performance was maintained in the BET
353 group, whereas there was a reduction in the control group. We had expected that the 4-week
354 preseason physical training program would improve the endurance performance of both
355 groups. Given that motivation did not differ significantly between pretest and posttest, we
356 speculate that the players had not fully recovered from the intense physical training regime
357 before completing the posttest. It is, therefore, possible that players were in a state of
358 functional overreaching when they completed the second 30–15 IFT. Regardless, the BET
359 group showed better intermittent running endurance than the control group. This is in line
360 with findings of previous studies showing that participants training with concurrent BET have
361 better endurance performance than participants performing standard physical training (control
362 group) after 6 to 12 weeks of training.^{10,11} It has been speculated that BET increases
363 endurance performance by inducing adaptations in brain areas such as the anterior cingulate
364 cortex, which are activated during the cognitive tasks used for BET.² This is relevant because
365 the anterior cingulate cortex is involved in mental fatigue and perception of effort^{2,22} which,

366 in turn, affect endurance performance,²³ including a Yo-Yo Intermittent Recovery Test ¹⁵ and
367 an intermittent high-intensity running test⁶ in soccer players and other team sport athletes.
368 Here, we also speculate that BET may have made the players more resilient to overreaching,
369 which has a strong psychological component.²⁴

370
371

372 *BET and Cognitive Performance*

373 We measured the psychomotor vigilance of the players before (fresh state) and after
374 (fatigued state) a demanding physical and cognitive task, namely, the RSA random test. As it
375 is the case for traditional brain training programs in young healthy adults,²⁵ BET did not
376 improve cognitive performance measured in optimal conditions (fresh state). However, the
377 results of our study show that BET improves psychomotor vigilance in a fatigued state.
378 Indeed, the BET group made 42% fewer lapses (with similar reaction times) at posttest
379 compared pretest, while the control group did not improve over time during the PVT
380 performed after the RSA. It is worth noting that lapses during this vigilance task are a more
381 sensitive indicator of alertness than simple reaction time.¹⁷ Thus, it seems that BET boosted
382 players' ability to sustain attention when fatigued by a previous bout of repeated sprints.
383 An improvement in performance was also evident for the Stroop test, with the BET group
384 responding 11% faster (with the same accuracy) from pretest to posttest compared with the
385 control group, which improved 4% after 4 weeks of training. Notably, this relatively
386 improved Stroop performance was obtained despite the test being perceived to be less
387 mentally demanding and requiring less effort by players in the BET group. The Stroop test is
388 a classic response inhibition test that has often been used to induce mental fatigue²⁶ and was
389 performed after a strenuous physical task (30–15 IFT). Therefore, the improved response
390 inhibition that characterized the BET group suggests greater resilience toward mental
391 fatigue.^{26,27} Improved inhibitory control in conditions of mental fatigue may be particularly
392 beneficial in terms of players' behavior on the pitch because research has shown that mental
393 fatigue reduces people's ability to control their aggressive behavior especially when
394 provoked.²⁸

395
396

396 *BET and Multitasking Performance*

397 In addition to using primarily physical (30–15 IFT) and primarily cognitive (PVT and
398 Stroop) tests, we tested the effects of BET using tests that combine anaerobic metabolism and
399 neuromuscular function with visuomotor and decision-making skills. The first of these
400 multitasking performance tests (the RSA random test) showed that the BET group improved
401 their performance more than the control group in the directional sprints but not in the linear
402 sprints after 4 weeks of training. While performance in the linear acceleration phase of the
403 RSA depends primarily on anaerobic metabolism and neuromuscular function,²⁹ performance
404 in the directional sprints is also determined by the player's ability to respond quickly to a
405 visual stimulus and decide the correct movement direction. Altogether, our findings suggest
406 that BET improved the cognitive component of this multitasking performance test assessing
407 physical and cognitive skills relevant to football. It is worth noting that we required players to
408 complete twice as many sprints (12 instead of 6) as the standard RSA. Given evidence that
409 mental fatigue is associated with poorer physical and technical performance in football⁵ and
410 decreased decision-making skill and visual search performance in basketball,³⁰ it is possible
411 that the *post* BET group experienced less effort during the physical task and thereby had
412 sufficient residual cognitive resources to focus better on the task, respond faster to visual
413 stimuli, and decide faster how to move during the task.
414 The positive effect of BET on multitasking performance was confirmed by the S-RAG. In our
415 version of the test, players continuously reacted to visual stimuli and decided which direction

416 to run while exercising at a high intensity and experiencing increasing fatigue. From pre to
417 posttest the BET group completed the test 8.9% faster, while the control group only 4.3%
418 faster. Moreover, BET group completed the test with 69% less errors, whereas the control
419 group made 21% fewer errors after 4 weeks of training. Faster reaction times and fewer hand
420 errors in this test may translate to better performance in a sport like football in which reactive
421 agility during intense phases of the game is thought to be an important skill. Furthermore,
422 increased resistance to mental fatigue may generalize to superior physiological, cognitive,
423 and technical³⁰ performance and thereby have fewer goals conceded during football
424 matches.³¹

425

426 *Study Limitations*

427 The current study yielded some important new findings that can be incorporated into
428 athletes' training schedules. However, some potential study limitations should be noted when
429 interpreting this evidence. First, the sample size was relatively small. The number of
430 participants recruited was limited by the size of the squad we had access to and the study
431 inclusion/exclusion criteria, such as injuries. Future studies should collect data from a number
432 of different clubs to increase the overall sample size and provide more robust evidence for or
433 against the BET in professional football players. Second, we asked players in the control
434 group to listen to emotionally neutral sounds for 20 to 30 minutes following the last daily
435 physical training session for 4 to 5 sessions per week. This control treatment was employed to
436 reduce threats to internal validity, like resentful demoralization and compensatory rivalry.
437 However, despite the choice of neutral emotional valence of the sounds, the absence of a true
438 control group with no treatment at all means that we cannot be entirely confident that the
439 differences in cognitive load and performance outcomes measured in this study were caused
440 by *post* BET. Although extremely unlikely, the differences observed between the 2 groups
441 may have been caused by the control treatment. Regardless of the certainty of its cause (*post*-
442 BET or the unlikely relaxing effects of the control treatment), our results suggest that higher
443 cognitive load during 4 weeks of training is associated with better improvements in various
444 measures of physical, cognitive, and multitasking performance. Third, players completed the
445 Stroop test after a demanding multitasking performance test (S-RAG), which may have
446 affected their Stroop performance. Therefore, we do not know whether the improvement in
447 response inhibition observed in the BET group would manifest itself in the fresh condition
448 (no previous S-RAG). Indeed, the PVT results suggest that the positive effects of BET on
449 cognitive performance may only be evident in fatigue conditions. Finally, we monitored
450 physical training load only using subjective ratings and HR recordings. Future investigations
451 could supplement these measures with GPS recordings to track external load.

452

453 **Practical Applications**

454 The findings of this study provide initial support for the inclusion of BET alongside basic
455 physical training in the overall training programming for professional football players.
456 Specifically, BET could be used to improve players' performance by increasing the cognitive
457 load of training without overloading the musculo-skeletal system and thereby mitigate
458 overuse injury risk. Importantly, the *post* BET protocol used in this study was well tolerated
459 by the players and could be adapted to the constraints of the preseason training environment.

460

461 **Conclusions**

462 The present study provides further evidence that BET improves endurance performance,
463 extending its impact to intermittent run- ning and professional athletes. Furthermore, it
464 provides initial evidence that BET may also improve psychomotor vigilance and inhibitory
465 control in fatigued conditions and multitasking performance, reinforcing the important role

466 played by the brain in sport performance.³² Given the importance of multitasking
467 performance and resilience to fatigue for professional athletes and other occupations like the
468 military, further research on the effects of BET on these performance outcomes is warranted.

469

470 ***Disclosure Statement***

471 No conflict of interest is reported in this research study.

472

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476

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478

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480

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Figure captions

Figure 1

30–15 IFT and RSA (random test) pre and post 4 weeks of training for BET and control groups. (A) 30–15 IFT maximum performance speed at completion. (B) RSA random test average of directional sprints. Error bars are 95% CI. BET indicates brain endurance training; IFT, Intermittent Fitness Test; RSA, repeated sprint ability. §Significant group × time interaction. *Main effect of time. #Significantly different from control group.

Figure 2

Cognitive performance pre and post the intervention for the BET and control groups. (A) Stroop reaction time across groups and time. (B) PVT number of lapses across groups and time before and after the RSA random test. §Significant group × time interaction. *Main effect of time. #Significantly different from control group. Error bars are 95% CI. BET indicates brain endurance training; CI, confidence interval; PVT, psychomotor vigilance test; RSA, repeated sprint ability.

Figure 3

S-RAG pre and post the intervention for the BET and control group. (A) S-RAG time to complete the test. (B) Reactive agility test. S-RAG number of hand errors. Error bars are 95% CI. BET indicates brain endurance training; S-RAG, soccer-specific reactive agility test §Significant group × time interaction. *Main effect of time. #Significantly different from control group.

Table 1. Training variables a Function of Group and Week

	Week 1		Week 2		Week 3		Week 4		Group			Week			Group × week		
	BET	Control	BET	Control	BET	Control	BET	Control	$F_{1,20}$	P	η_p^2	$F_{3,60}$	P	η_p^2	$F_{3,60}$	P	η_p
Time in HR zones, min																	
Zone 1 (<60%)	186 (32)	154 (45)	234 (52)	177 (61)	60 (25)	61 (34)	80 (22)	83 (15)	1.361	.257	.08	15.01	<.001*	.31	1.781	.161	.07
Zone 2 (60%–70%)	158 (25)	162 (23)	170 (24)	164 (42)	69 (9)	61 (13)	66 (11)	84 (32)	1.546	.228	.09	14.61	<.001*	.49	0.239	.863	.01
Zone 3 (70%–80%)	128 (24)	136 (31)	130 (37)	156 (41)	86 (19)	69 (22)	78 (21)	72 (16)	0.306	.586	.07	20.33	<.001*	.41	0.594	.624	.01
Zone 4 (80%–90%)	107 (29)	138 (40)	90 (31)	107 (33)	92 (28)	84 (34)	91 (31)	92 (26)	0.721	.406	.09	4.98	.004*	.15	0.997	.407	.04
Zone 5 (90%–100%)	46 (17)	59 (14)	22 (11)	24 (8)	30 (15)	39 (17)	37 (12)	41 (20)	0.178	.678	.04	23.31	<.001*	.22	2.082	.113	.06
Total	625 (27)	649 (23)	646 (32)	628 (44)	337 (23)	314 (25)	352 (25)	372 (26)	1.358	.258	.10	22.01	<.001*	.47	0.878	.458	.10
NASA-TLX																	
Mental demand	75 (4)	55 (5)	80 (5)	63 (6)	70 (4)	55 (5)	64 (3)	52 (5)	27.33	<.001*	.15	3.301	.026*	.28	1.967	.132	.08
Physical demand	51 (3)	49 (4)	61 (4)	63 (5)	77 (5)	81 (3)	79 (6)	77 (5)	2.240	.150	.09	3.423	.023*	.34	1.733	.171	.01
Effort	71 (8)	74 (5)	91 (7)	89 (6)	80 (4)	78 (5)	75 (3)	77 (5)	2.633	.120	.09	3.831	.014*	.14	1.167	.335	.01

Abbreviations:

- BET: brain endurance training.
- HR: heart rate.
- NASA-TLX: NASA Task Load Index.

Note: BET and control values are presented as mean (SD), * $p < .05$

Figure 1

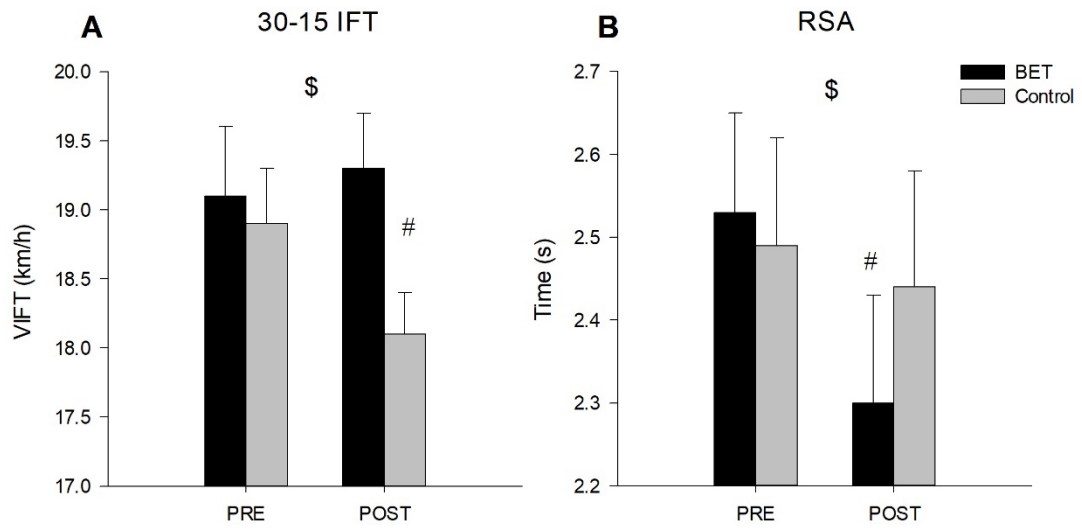


Figure 2

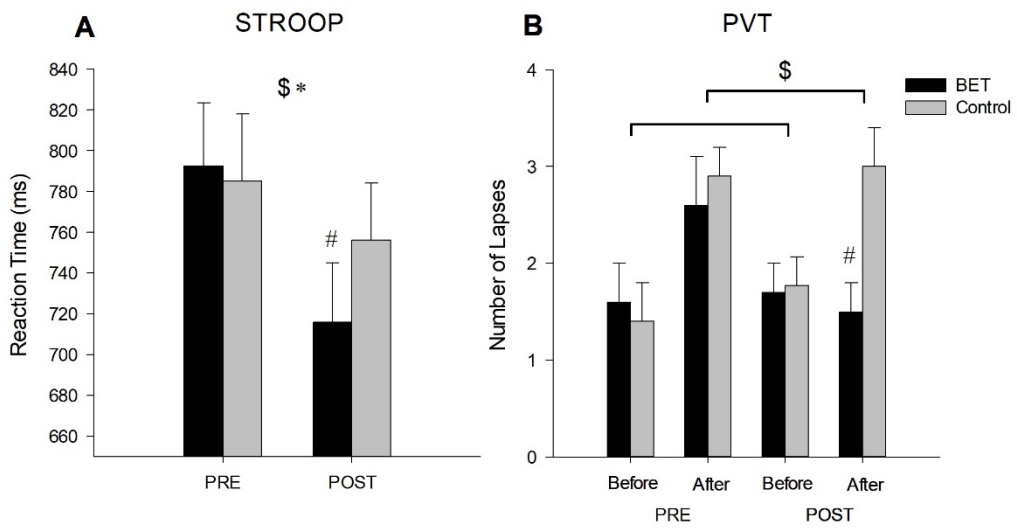


Figure 3

