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BRAIN ENDURANCE TRAINING IMPROVES PHYSICAL, COGNITIVE AND MULTI-TASKING PERFORMANCE IN PROFESSIONAL FOOTBALL PLAYERS

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35 Abstract

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Purpose: Brain endurance training (BET)-the combination of physical training with 37 38 mentally fatiguing tasks—could help athletes adapt and increase their performance during sporting competitions. Here we tested whether BET completed after standard physical 39 training improved physical and mental performance more than physical training alone during 40 41 a preseason football training camp. *Methods*: The study employed a pretest/training/posttest design, with 22 professional football players randomly assigned to BET or a control group. 42 Both groups completed 40 physical training sessions over 4 weeks. At the end of a day of 43 44 physical training, the BET group completed cognitive training, whereas the control group listened to neutral sounds. Players completed the 30-15 Intermittent Fitness Test, repeated 45 sprint ability random test, soccer-specific reactive agility test, and Stroop and psychomotor 46 47 vigilance tests pretraining and posttraining. Mixed analysis of variance was used to analyze the data. *Results*: In the posttest (but not pretest) assessments, the BET group consistently 48 outperformed the control group. Specifically, the BET group was faster (P=.02-.04) than the 49 control group during the 30–15 Intermittent Fitness Test, the directional phase of the repeated 50 51 sprint ability random test, and the soccer-specific reactive agility test. The BET group also made fewer errors (P = .02) during the soccer-specific reactive agility test than the control 52 group. Finally, the BET group responded faster (P = .02) on the Stroop test and made fewer 53 54 (P = .03) lapses on the psychomotor vigilance test than the control group. *Conclusion*: The inclusion of BET during the preseason seems more effective than standard physical training 55 alone in improving the physical, cognitive, and multitasking performance of professional 56 57 football players. 58

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

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66 Introduction

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Mental fatigue has been defined as a psychobiological state induced by prolonged periods 68 of demanding cognitive activity, which is characterized by feelings of tiredness and lack of 69 energy.^{1,2} Football players are required to react to various stimuli, make quick decisions, 70 remember and switch strategies, and stay alert during the whole match. As a result, they can 71 develop mental fatigue over time.³ Stressors other than playing football (eg, travel and 72 education) can also induce mental fatigue.⁴ With regards to performance, this is not optimal 73 because research studies have demonstrated that mental fatigue can impair aerobic capacity,⁵ 74 intermittent running velocity, $\frac{6}{2}$ decision making, $\frac{5.6}{2}$ technical skills, $\frac{5.7}{2}$ and psychomotor 75 vigilance.⁸ Therefore, it is necessary to develop strategies to reduce the negative effects of 76 77 mental fatigue in football players.

Given evidence that physical and mental effort involve several overlapping brain regions,² 78 Marcora et al.¹⁰ proposed an innovative training method—brain endurance training (BET)— 79 to increase the cognitive load of physical training to make athletes more resilient to mental 80 fatigue and improve their endurance performance. Their seminal study showed that the 81 82 addition of a 60-minute cognitive task to a standard physical training program focusing on endurance (ie, a 60-min cycling task performed 3 times per week for 12 wk) led to greater 83 improvements in endurance measured with a cycling time to exhaustion test. The improved 84 85 endurance performance with BET was explained in terms of brain adaptations to the systematic cognitive overload resulting in a reduction in the perception of effort during the 86 cycling to exhaustion test. The benefit of concurrent BET for endurance performance has 87 88 since been replicated by another research group using a rhythmic handgrip exercise task.¹¹ Taken together, these studies argue for a beneficial effect of BET on endurance performance 89 when the cognitive task is performed *during* exercise. However, adding a concurrent 90 91 cognitive task may not always be practical during football training on the field. Therefore, other combinations of cognitive training and physical training should be investigated. For 92 example, the coach could ask the players to perform a demanding cognitive task before the 93 physical training session (pre BET) so that they train in a state of mental fatigue. Another 94 possibility is to perform a demanding cognitive task during the recovery periods of a high-95 intensity interval training session (intermixed BET) so that, while the body recovers between 96 the exercise bouts, the brain remains highly engaged. Finally, it is possible to add the 97 demanding cognitive task immediately after the session when the players are fatigued by the 98 physical training (post BET). Potentially, all of these combinations could induce positive 99 brain adaptations and increase the overall training load imposed on the players without 100 101 increasing the physical load. In injured athletes or athletes at high risk of overuse injuries, coaches could also use BET to maintain the overall training load when the physical load is 102 reduced. Given these potential practical applications, further experimental research on the 103 104 effects of BET is warranted. Such research should also include other outcomes in addition to endurance performance. Indeed, because of its multitasking nature, BET may also help to 105 improve performance when physical and cognitive tasks have to be performed 106 simultaneously (dual tasking) or in rapid succession (task switching), which would obviously 107 be highly beneficial in football players and other team sports in which optimal multitasking 108 performance is required. 109

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

- 116 Methods
- 117

118 Participants

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

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132 Experimental Design

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

139 *Testing*

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

During testing session 2, players performed the 30 to 15 intermittent fitness test (IFT), $\frac{12}{12}$ 153 154 an incremental running test de- signed to measure endurance in team sport athletes. The velocity in kilometers per hour of the final and fully completed stage was recorded as the 155 velocity IFT. This test has been shown to have good test-retest reliability with a typical error 156 of measurement to be of 0.3 km/h (intraclass correlation coefficient = .96). Heart rate (HR) 157 and a capillary blood sample were obtained upon task completion. Players rested for 30 158 minutes before completing a 30-minute incongruent Stroop color-word test $\frac{13}{13}$ on a personal 159 computer. Reaction time (in milliseconds) and accuracy (in percentage of correct answers) 160 were computed. Finally, players completed a NASA task load index $(NASA-TLX)^{14}$ to assess 161 the demands of the Stroop test. 162

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

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

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

192

193 *Training interventions*

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

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

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

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

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228 Physiological Measures

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

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235 *Psychological Measures*

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

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242 Statistical analysis

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

252

253254 Results

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256 *Training Variables*

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

266 *Motivation*

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

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272 *Physical Performance*

The ANOVA yielded a group \times time interaction for velocity at the end of the 30–15 IFT 273 274 (F1,20 = 5.12, P = .04, η 2p = .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 velocity (F1,20 = 2.09, P = .14, η 2p = :05). No group (F1,20 = 0.85, P = .37, η 2p = .04), time 276 (F1,20 = 1.68, P = .21, η 2p = .08), or group × time (F_{1,20} = 1.83, P = .19, η 2p = .08) effects 277 278 were found for blood lactate concentration (BET pre: 10.1 [1.5], BET post: 9.6 [2]; control pre: 10.5 [1.8], control post: 9.7 [1.9]). Similarly, HR at the end of the fitness test (BET pre: 279 194 [10], BET post 192 [8]; control pre: 196 [9], control post: 191 [11]) did not show any 280 effects for group ($F_{1,20} = 0.30$, P = .59, $\eta 2p = .02$), time ($F_{1,20} = 2.90$, P = .10, $\eta 2p = .13$), 281 282 or group × time ($F_{1,20} = 2.56$, P = .13, $\eta 2p = .11$).

284 *Cognitive Performance*

285 In the Stroop test, there was a group \times time interaction for reaction time ($F_{1,20} = 6.26$, P =.02, $\eta 2p = .13$; Figure <u>2A</u>). Reaction times decreased from pretest to posttest in both groups 286 $(F_{1,20} = 6.38)$, P = .02, $\eta 2p = .26)$, and, importantly, the BET group was faster than control 287 288 at posttest (P < .001). Accuracy did not vary as a function of group (F1,20 = 0.13, P = .91, $\eta^2 p = .00$), time (F1,20 = 0.31, P = .58, $\eta^2 p = .02$), and group × time (F1,20 = 0.12, P = .73, 289 $\eta 2p = .01$). Accuracy was universally high (grand mean: 94% [2%] correct responses). The 290 291 NASA-TLX subscales completed after the Stroop test revealed group × time interactions for mental demand (F1,20 = 16.61, P < .001, η 2p = .17) and effort (F1,20 = 17.55, P < .001, η 2p 292 = .24). Follow-up tests revealed that at posttest, the Stroop test was less (Ps = .02-.03) 293 demanding for BET (39 [6]) than control (71 [7]) and effortful for BET (48 [4]) than control 294 (69 [5]). No main effects of time were noted for mental demand (F1,20 = 0.40, P = .54, η 2p = 295 .02) and effort (F1,20 = 0.01, P = .92, η 2p = .00). No effects emerged for physical demand 296 (group $[F1,20 = 0.50, P = 0.53, \eta 2pp = :03]$, time $[F1,20 = 1.84, P = 0.21, \eta 2pp = :08]$, and 297 group by time $[F1,20 = 0.39, P = .62, \eta 2p = :03]$, grand mean 15 [9]). No significant effects 298 were found for lapses when players performed the PVT before the RSA (fresh state; group 299 $[F1,20 = 0.78, P = .55, \eta 2p = .02]$, test $[F1,20 = 0.99, P = .30, \eta 2p = .02]$, and group × time 300 $[F1,20 = 0.47, P = .46, \eta 2p = .01]$; grand mean 1.8 [0.3] lapses; Figure 2B). However, in the 301 PVT performed after the RSA (fatigued state), there was a significant group × time 302 interaction for number of lapses (F1,20 = 5.38, P = .03, η 2p = .14; Figure 2B). Follow-up 303 304 tests revealed that, compared with the control group, the number of lapses in the fatigued state was significantly lower in the posttest in the BET group (P = .01). No main effect of 305 time was found for lapses (F1,20 = 1.89, P = .17, η 2p = :04). No significant effects emerged 306 for reaction time in either the fresh state (group $[F1,20=0.49, P=.49, \eta 2p=.02]$, time $[F1,20=0.49, P=.49, \eta 2p=.02]$, time [F1,20=0.49, P=.49, P=.49, q=.49, q=.49,307 = 1.94, P = .18, $\eta 2p$ = .09], and group × time [F1,20 = 0.43, P = .52, $\eta 2p$ = .02]; grand mean 308 331 [22] ms) or in the fatigued state (group [F1,20 = 0.78, P = .40, $\eta 2p = .04$], time [F1,20 = 309 1.14, P = .28, $\eta 2p = .04$], and group × time [F1,20= 0.27, P = .66, $\eta 2p = .02$]; grand mean 310 315 [25] ms). 311

312

313 *Multi-tasking performance*

The ANOVA uncovered a group × time interaction effect for the directional sprints in the RSA (F1,20 = 4.66, P = .04, η 2p = .05; Figure 1B): Follow-up tests revealed that the BET

group was faster than the control group (P = .04) at posttest. No main effect of time was 316 found (F1,20 = 3.09, P = .09, η 2p = .08). Analysis of the linear acceleration phase of the RSA 317 revealed neither main effect of group (F1,20 = 1.33, P = .26, $\eta 2p$ = .06) nor main effect of 318 time (F1,20 = 2.10, P = .16, η 2p = .06), and no interaction (F1,20 = 0.07, P = .80, η 2p = .00) 319 (grand mean: 2.3 [0.2]). The ANOVA found a group \times time interaction on time to complete 320 the S-RAG test (F1,20 = 5.41, P = .03, η 2pp = .11; Figure 3A), with both groups faster at 321 posttest than pretest (F1,20 = 7.70, P = .01, $\eta 2p$ = .10) and the BET group faster than control 322 at posttest (P = .04). A group \times time interaction for hand errors (F1,20 = 6.36, P = .02, η 2p = 323 .18; Figure 3B) revealed that although both groups erred less at posttest than pretest (F1,20 = 324 4.66, P = .04, $\eta 2p = .10$), the BET group made fewer mistakes than control at posttest (P =325 .03). Blood lactate concentration at completion of S-RAG (BET pre: 11.4 [1.8], BET post: 326 12.1 [2.1]; control pre: 11.9 [2.4], control post: 12.2 [2.5]) did not show any group (F1,20 = 327 1.67, P = .21, $\eta 2p$ = .07), time (F1,20 = 2.60, P = .11, $\eta 2p$ = .08), or group × time (F1,20 = 328 $0.85, P = .37, \eta 2p = .04)$ effects. 329

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332 Discussion333

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

350

351 *BET and Physical Performance*

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

in turn, affect endurance performance,²³ including a Yo-Yo Intermittent Recovery Test ¹⁵ and
an intermittent high-intensity running test<u>6</u> in soccer players and other team sport athletes.
Here, we also speculate that BET may have made the players more resilient to overreaching,
which has a strong psychological component.²⁴

370 371

372 *BET and Cognitive Performance*

We measured the psychomotor vigilance of the players before (fresh state) and after 373 (fatigued state) a demanding physical and cognitive task, namely, the RSA random test. As it 374 375 is the case for traditional brain training programs in young healthy adults, $\frac{25}{25}$ BET did not improve cognitive performance measured in optimal conditions (fresh state), However, the 376 results of our study show that BET improves psychomotor vigilance in a fatigued state. 377 378 Indeed, the BET group made 42% fewer lapses (with similar reaction times) at posttest compared pretest, while the control group did not improve over time during the PVT 379 performed after the RSA. It is worth noting that lapses during this vigilance task are a more 380 sensitive indicator of alertness than simple reaction time.¹⁷ Thus, it seems that BET boosted 381 players' ability to sustain attention when fatigued by a previous bout of repeated sprints. 382

An improvement in performance was also evident for the Stroop test, with the BET group 383 responding 11% faster (with the same accuracy) from pretest to posttest compared with the 384 385 control group, which improved 4% after 4 weeks of training. Notably, this relatively improved Stroop performance was obtained despite the test being perceived to be less 386 mentally demanding and requiring less effort by players in the BET group. The Stroop test is 387 388 a classic response inhibition test that has often been used to induce mental fatigue^{$\frac{26}{6}$} and was performed after a strenuous physical task (30-15 IFT). Therefore, the improved response 389 inhibition that characterized the BET group suggests greater resilience toward mental 390 fatigue.^{26,27} Improved inhibitory control in conditions of mental fatigue may be particularly 391 beneficial in terms of players' behavior on the pitch because research has shown that mental 392 fatigue reduces people's ability to control their aggressive behavior especially when 393 provoked.²⁸ 394

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396 *BET and Multitasking Performance*

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

The positive effect of BET on multitasking performance was confirmed by the S-RAG. In our version of the test, players continuously reacted to visual stimuli and decided which direction

to run while exercising at a high intensity and experiencing increasing fatigue. From pre to 416 posttest the BET group completed the test 8.9% faster, while the control group only 4.3% 417 faster. Moreover, BET group completed the test with 69% less errors, whereas the control 418 group made 21% fewer errors after 4 weeks of training. Faster reaction times and fewer hand 419 errors in this test may translate to better performance in a sport like football in which reactive 420 agility during intense phases of the game is thought to be an important skill. Furthermore, 421 increased resistance to mental fatigue may generalize to superior physiological, cognitive, 422 and technical³⁰ performance and thereby have fewer goals conceded during football 423 matches. $\frac{31}{2}$ 424

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426 *Study Limitations*

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

453 **Practical Applications**

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

461 **Conclusions**

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The present study provides further evidence that BET improves endurance performance, extending its impact to intermittent run- ning and professional athletes. Furthermore, it provides initial evidence that BET may also improve psychomotor vigilance and inhibitory control in fatigued conditions and multitasking performance, reinforcing the important role played by the brain in sport performance.³² Given the importance of multitasking
performance and resilience to fatigue for professional athletes and other occupations like the
military, further research on the effects of BET on these performance outcomes is warranted.

- 469470 *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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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. $Significant group \times$ 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 \times 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}	Р	η_p^2	$F_{3,60}$	Р	η_p^2	F _{3,60}	Р	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

