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Original research

Brain endurance training improves soccer-specific technical skills and cognitive performance in fatigued professional soccer players

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ABSTRACT

Objectives: Brain Endurance Training (BET) — the addition of mentally fatiguing cognitive tasks to standard physical training — could improve performance in soccer. We tested whether BET, with cognitive tasks intermixed with physical training activities, improved players' cognitive and soccer-specific technical performance compared to physical training alone when fresh and fatigued.
Design: The study employed a pre/training/midtest/training/posttest design.
Methods: 31 professional male soccer players were randomly assigned to BET or control groups and completed 18 physical training sessions over 6 weeks. In between the physical training activities, the BET group completed demanding cognitive tasks, whereas the control group rested. Players completed the Loughborough soccer passing (LSPT) and shooting test (LSST) before and after completing a 30-min Stroop task. A brief psychomotor vigilance test (PVT-B), a visual analog rating of mental fatigue (MF-VAS), and rating of perceived exertion (RPE) were measured during testing and training.
Results: During testing, the 30-min Stroop task elicited a state of MF, confirmed by higher subjective ratings ($P < .01$). Compared to pre-testing, at mid- and post-testing, the BET group improved passing (all $P < .01$), shooting (all $P < .01$), and PVT-B performance (all $P < .01$) when tested after (fatigued) but not before (fresh) the Stroop task, whereas the control group did not change performance either way. During training the BET group reported higher MF ($P < .01$) and exhibited slower PVT-B responses ($P < .01$) compared to control.
Conclusions: Intermixed BET was more effective than physical training alone at improving cognitive and soccer-specific technical performance of professional soccer players when fatigued.

Practical implications

- BET may increase resistance to mental fatigue in professional soccer players, and therefore help to maintain skilled performance, when it may otherwise decrease when players are mentally fatigued.
- BET increases the overall cognitive demand of a training session without overloading the cardiorespiratory and musculoskeletal systems. It is time efficient and well integrated in the training session.
- BET may prove beneficial in reducing the decline of performance in soccer seasons which includes several matches over several months and accumulated mental and physical fatigue.

1. Introduction

Fatigue causes professional soccer players to perform worse during matches.[1] Research evidence demonstrates impaired technical performance, reduced ball possession, fewer successful passes and shots, and more goals conceded in the second half of matches.[2] A deeper understanding of the mechanisms underlying the fatigue-performance relationship is crucial to mitigate its deleterious effects and thereby enhance soccer performance.[3,4]

Playing soccer elicits mental and physical fatigue.[3,5] Mental fatigue is a psychobiological state arising from prolonged and demanding cognitive tasks, characterized by feelings of weariness and diminished energy.[6] Soccer players must respond to multiple stimuli, make rapid decisions, adapt quickly to situations, and stay focused during the entire match. Players may experience mental fatigue as a consequence of these cognitive demands.[4] Recent research has examined the impact of mental fatigue on the physical, technical, and cognitive performance of

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soccer players.[4] Smith and colleagues[7] observed declines in soccer-specific markers of aerobic endurance capacity and passing/shooting proficiency. Later studies have corroborated and extended these preliminary findings, documenting deficiencies in dribbling accuracy, decision-making, and peripheral vision in mentally fatigued soccer players.[8,9] Accordingly, countermeasures are needed that mitigate the adverse consequences of mental fatigue in soccer players.

Marcora et al.[10] developed a novel training method – Brain Endurance Training (BET) – that augmented the cognitive demands of physical training in order to develop the ability to withstand mental fatigue and enhance endurance performance. Their seminal study demonstrated that adding cognitive activity concurrently to a physical endurance training program (a 60-min cycling task completed three times per week for 12 weeks) extended time to exhaustion more than standard training alone. Studies have replicated this initial finding[11,12] and established the effectiveness of BET for endurance exercise. Staiano et al.[13] demonstrated the benefits of BET in professional soccer players who trained for 4 weeks using a modified BET protocol, where mentally fatiguing cognitive tasks were completed subsequent to physical training tasks (*post* BET). The study found that the BET group outperformed the exercise-only control group, in terms of soccer-specific reactive agility and repeated sprinting. Furthermore, the BET group exhibited enhanced inhibitory control and maintained attentional focus in the post-training assessments compared to the control group. Importantly, the impact of BET on soccer-specific technical skills, such as shooting and passing, has yet to be determined.

Studies have explored the effects of other forms of BET on sport performance. One time-efficient protocol is to perform cognitive tasks during the recovery periods between physical tasks.[14] This *intermixed* BET (iBET) means that the brain remains loaded while the body recovers between exercise bouts.[15] Its efficacy has been demonstrated for paddle shot performance.[15] Furthermore, given that BET seeks to improve resilience against mental fatigue, BET might be expected to improve performance more when fatigued than rested. However, two studies by Dallaway and colleagues show that BET improved physical performance under both fresh and fatigued conditions.[11,16] A recent study[15] confirmed that iBET improved paddle shot speed and accuracy when players were fatigued but not when they were rested. BET's benefit for psychomotor performance has yet to be confirmed in other sports, such as soccer. Previous studies examining the effects of mental fatigue on physical performance highlight the negative impact of mental fatigue on technical skills. Moreover, the previous study on BET and soccer performance[13] showed a BET-related improvement in the directional phase of a repeated sprint ability test but not in the linear accelerating phase and only in fresh conditions. This result suggests that BET could be effective in improving more technical skills in soccer performance alongside endurance performance in fresh and fatigued states.

The overall objective of the current study was to assess the impact of iBET on soccer-specific technical and cognitive performance in professional soccer players. The study purposes were twofold. Our first study purpose was to determine the effect of iBET on passing and shooting performance. We hypothesized that iBET would improve shooting and passing outcomes performed with the Loughborough soccer passing (LSPT) and shooting (LSST) tests. Our second study purpose was to determine the moderating influence of mental fatigue on BET-related changes in performance. We hypothesized that the benefits of iBET would be greater when the players were fatigued by a prior cognitive task compared to when they were feeling fresh. We argued that the requirements of the Loughborough tests, in which multiple passes and shots are required, are both mentally and physically demanding, and fatiguing over time. Therefore, iBET would improve performance in the fresh condition by boosting the resilience to fatigue over time during the series of passes and shots, and increasing resilience to mental fatigue, and performance when in a mentally fatigued state. We also hypothesized that iBET would improve cognitive performance, assessed using the psychomotor vigilance task, with greater improvement when mentally fatigued than fresh.

2. Methods

Thirty-one professional male soccer players from a national Portuguese second division (mean [SD], age 26.32 [8.41] years, height 184.31 [12.11] cm, and weight 77.42 [9.76] kg) were recruited. They signed an informed consent form to participate in this study, which was approved by the Ethics Committee of the University of Extremadura in accordance with the Declaration of Helsinki. Players with injuries or specific training plans were excluded. All players received written instructions describing the study protocol but were naïve to its overall aims and hypotheses (they were informed that we were testing cognition). The sample size was based on a previous BET study in soccer[13] and allowed for a potential 20 % attrition. The study employed a stratified randomized pre-test/training/mid-test/training/post-test controlled design (see Fig. 1). After baseline testing at week 0 (pretest), participants were stratified according to playing position (goalkeepers, defenders, midfielders, forwards) and randomly assigned to either an iBET group ($n = 15$) or Control group ($n = 16$). Players were tested again at the end of weeks 3 and 6.

Players performed physical and cognitive tests in 4 sessions: one familiarization session and three experimental sessions (pre-test, mid-test, post-test). All testing sessions were conducted in the same facility and at the same time of day. Prior to each testing session, players followed a standardized routine regarding sleep, recovery, meals, hydration, supplementation, and medication. Temperature and humidity were monitored and kept constant. At the start of each testing session, players completed a motivation questionnaire and a standardized physical warmup. During testing sessions, no verbal encouragement was provided by the experimenter.

During the familiarization session, players completed the battery of physical and cognitive tests and questionnaires to familiarize them with the assessments. During the experimental sessions, players completed three 90-min sessions at 0 (pre-test), 3 (mid-test), and 6 (post-test) weeks (Fig. 1). In each testing session, players provided a visual analog scale rating of mental fatigue (M-VAS), completed a 3-min brief psychomotor vigilance test (PVT-B) (UMH-MEMTRAIN, Elche, Spain), and performed versions of the Loughborough soccer passing (LSPT) and shooting (LSST) tests before and after completing a 30-min incongruent Stroop task (UMH-MEMTRAIN, Elche, Spain), a response inhibition test which elicits mental fatigue,[9] on a desktop computer. During the LSPT, 16 passes (distance of either 4 m or 3.5 m) were tested. Specifically, a colored (red, green, yellow, blue) piece of paper (0.6×0.3 m) was attached to each of four gymnasium benches positioned as a rectangle around the player that served as targets. Passes were performed in randomized order selected by an investigator. Participants were instructed to complete the 16 passes as fast as possible, while minimizing errors. The performance outcome measures included original time (time taken to complete the 16 passes), penalty time (time added for errors, inaccurate passes, and slow performance), and performance time (original time + penalty time). Penalty time was calculated according to the following criteria: +5 s for completely missing the bench or passing to the wrong bench; +3 s for missing the target area; +3 s for handling the ball; +2 s for passing the ball from outside of the passing area; +2 s if the ball touched any cone; +1 s for every second taken over the allocated 43 s to complete the test; and +1 s for each pass that hit the 10-cm strip in the middle of the target. This tool was used in previous soccer studies.[7,17] In the LSST, participants began 20 m away from the goal line, with their back to the goal. They were encouraged to sprint 6 m to two cones (left or right) positioned 6 m behind them. Participants then returned, kicked a ball against a bench before controlling and shooting the ball. Participants then sprinted past a stationary goalkeeper to replicate following their shot in a game. Each trial comprised 10 shots (5 with each foot in a

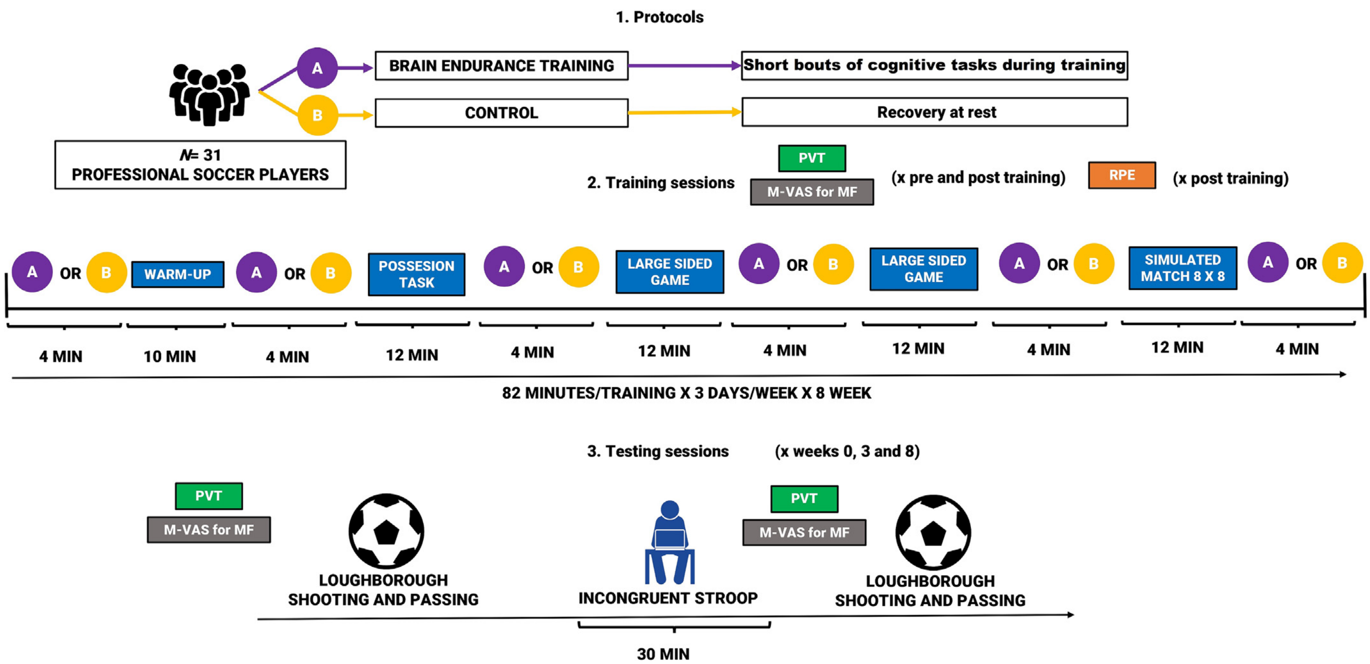

Fig. 1. Schematic of the experimental protocol.
PVT: psychomotor vigilant task; M-VAS: mental fatigue visual analog scale; RPE: rating of perceived exertion.

randomized order), separated by 1-min rest periods. One of six random trial orders was selected for each participant.

Performance was assessed by shot accuracy and shot sequence time. Shot accuracy was calculated as the mean of the total points accumulated from all shots on target. Score zones were arranged to encourage shooting toward the corners of the goal, and points were only scored if the ball struck the open space of the goal (opposite side to the goalkeeper). Shots that were attempted from outside of the shooting area were ignored.[17] Originally, we planned to calculate shot speed, however, the radar we were using malfunctioned and so we were unable to examine the shot speed data. Moreover, we did not implement the usual 8.5 s. time limitation during the shooting test in order to assess if the mental fatigue manipulation increased the players' performance time. We told players that investing more time to shoot would result in worse performance.

All players completed 18 physical training sessions over a 6-week period (excluding recovery and tapering sessions) under the supervision of the club's physical trainer and a researcher. They were instructed to follow the prescribed physical training program without completing any extra physical training sessions in order to standardize the impact of physical training on mid-test and post-test performance. Both groups completed the same physical training (stratified by field position). Training intensity, frequency, load, and type of training were monitored by the physical trainer, coach, and researcher. To assess weekly training load, M-VAS and PVT-B measured the cognitive load using tablet computers running the SOMA-NPT app (Soma Technologies, Lucerne, Switzerland) and RPE measured the physical load.[15,18]

The iBET group completed 4-min cognitive tasks intermixed with the physical training blocks (Fig. 1) for 24 min of cognitive tasks out of a total of 80–85 min of overall training per session. Previous studies demonstrated that mental fatigue and subsequent performance can depend on the demands (intensity) of the cognitive task rather than simply the duration of the task.[19] Accordingly, here we used short high intensity cognitive tasks. Specifically, players performed one of three cognitive tasks – flanker task, go/no-go task, AX-continuous performance test (AX-CPT) – using the SOMA-NPT app (Soma Technologies, Lucerne, Switzerland) running on a tablet computer. All three tasks involve the response inhibition cognitive operation, induce mental fatigue, and have been used in similar training studies.[12–14] Participants were instructed to choose and complete one of the three cognitive tasks in each block in each training session, while trying to ensure balance between the three cognitive tasks across the 6 weeks of training. The difficulty of each task was increased every 2 weeks to account for cognitive adaptation by adding distracting cues, shortening interstimulus intervals, and/or introducing additional demands, such as stop-and-go.[12] This protocol was previously used in a similar training study using BET.[12] To mitigate any placebo effect, participants were told that the tasks assessed their cognitive performance during the season rather than being a new form of training. The control group rested and sat (as per the iBET group, without performing any cognitive task) between exercise tasks during each physical training session.

Markers of mental fatigue during testing and at the beginning and end of each training session were obtained using subjective (M-VAS) and behavioral (PVT-B) assessments. With the M-VAS, participants were asked "*How mentally fatigued do you feel*?" and responded by placing a mark on a 10-cm line, anchored by "not at all fatigued" and "completely fatigued".[14] Mental fatigue was defined to the athletes as subjective feeling of mental tiredness and drain, lack of energy, and decreased motivation, alertness and attention.[4] In the 3-min Brief Psychomotor Vigilance Task (PVT-B), participants were presented with a visual stimulus (1–4 s interstimulus interval) in the center of a tablet computer and were required to respond by pressing the touchscreen as fast as possible; reaction time was recorded.[20] At completion of each training session perceived physical effort was measured using the CR10 Borg RPE scale.[21]

All data are presented as mean ± one standard deviation unless otherwise stated. A series of 2 group (*i*BET, Control) × 3 time (0, 3, 6 weeks) × 2 test (before Stroop, after Stroop) analyses of variance (ANOVAs) were performed on the measures of soccer performance, M-VAS ratings, and PVT-B responses during the testing sessions. A series of 2 group (*i*BET, Control) × 6 week (1, 2, 3, 4, 5, 6) ANOVAs were performed on RPE ratings, MF-VAS ratings, and PVT-B responses measured after each training session. These training data were averaged for each week (i.e., 3 training sessions per week) to yield values for each of the 6 weeks of training. Significant group × time × test interactions were followed up with paired *t* tests for the simple main effects of time, group and test. Significance was set at 0.05 (2-tailed) for all analyses. The effect sizes for the ANOVAs were calculated as partial eta-squared

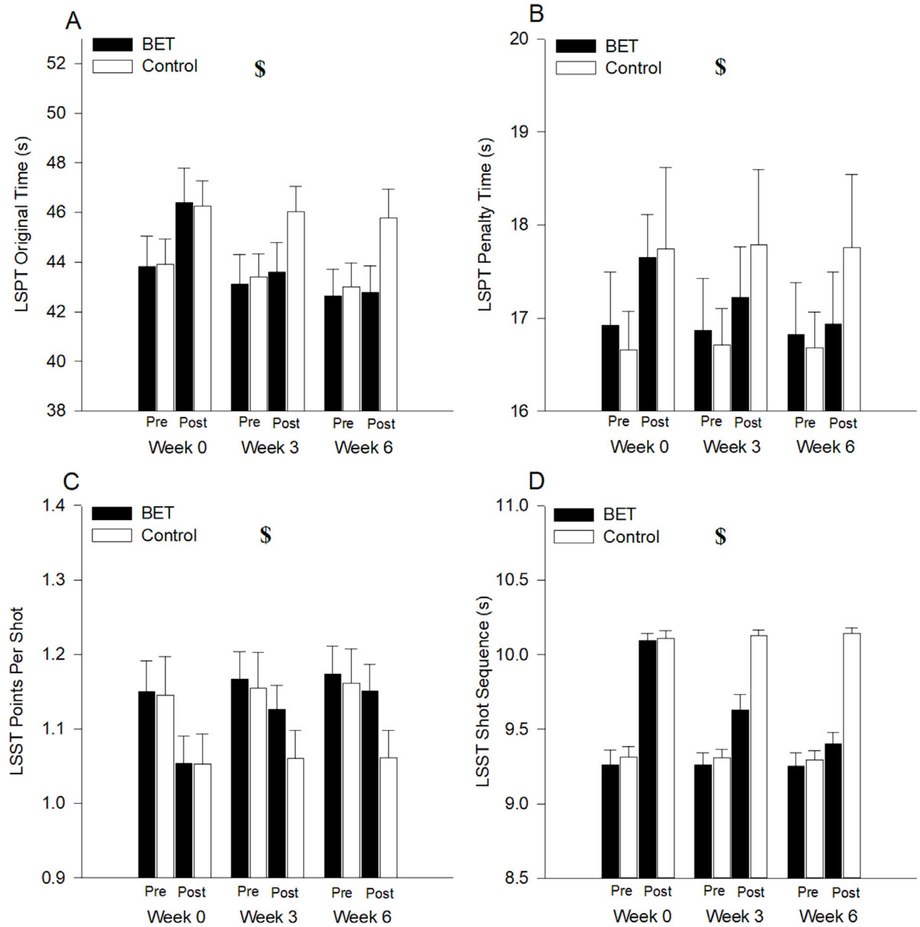

Fig. 2. LSPT and LSST soccer-specific technical performance at weeks 0, 3 and 6, pre and post Stroop task for the iBET and control groups.
(A) LSPT Original time across groups and time pre (before) and post (after) the Stroop task. (B) LSPT Penalty time across groups and time pre (before) and post (after) the Stroop task. (C) LSST Points per shot across groups and time pre (before) and post (after) the Stroop task. (D) LSST shot sequence time across groups and time pre (before) and post (after) the Stroop task.
$Significant group × time × test. Error bars indicate standard deviation.
LSPT indicates Loughborough soccer passing test; LSST indicates Loughborough soccer shooting test; iBET indicates intermixed brain endurance training.

(η^2p), with 0.02, 0.13, and 0.26 indicating small, medium, and large effects, respectively. Data analysis was conducted using the Statistical Package for Social Science (SPSS, version 29).

3. Results

The 2 group × 3 time × 2 test ANOVAs yielded large time and test main effects for all performance measures, with passing and shooting improving with time and deteriorating after compared to before the 30-min Stroop task. Importantly, large group by time by test interaction effects were found for each measure (see Fig. 2 and Table 1). In all cases, passing (Fig. 2A and B) and shooting (Fig. 2C and D) were consistently worse after compared to before the Stroop task in the Control group whereas passing and shooting times were slowed and the performances were impaired less and less by the Stroop task as training progressed for the iBET group. In brief, the impact of the Stroop task was equally large at weeks 0, 3 and 6 for the Control group but was greatest at week 0, less at week 3, and least at week 6 for iBET, with no before-after differences

Table 1
Summary of the key findings of the 2 group (iBET, Control) by 3 time (0, 3, 6 weeks) by 2 test (before Stroop, after Stroop) ANOVAs on soccer passing (original time, drive time) and shooting (points per shot, shot sequence time) performance, M-VAS (0–10) and PVT-B RT (ms) during testing.
Note: iBET indicates intermixed brain endurance training; M-VAS indicates mental fatigue visual analog scale; PVT-B RT indicates brief psychomotor test vigilance reaction time performance.

Measures	Group		Time		Test		Group × time		Group × test		Group × time × test	
	F (1, 29)	η^2_p	F (2, 28)	η^2_p	F (1, 29)	η^2_p	F (2, 28)	η^2_p	F (1, 29)	η^2_p	F (2, 28)	η^2_p
Original time	6.94**	0.19	130.53***	0.90	1545.22***	0.98	46.35***	0.77	265.22***	0.90	218.75***	0.94
Penalty time	0.62	0.02	67.71***	0.83	72.77***	0.72	47.92***	0.77	15.27***	0.35	34.46***	0.71
Points per shot	4.83*	0.14	148.32***	0.91	633.56***	0.96	66.41***	0.83	52.10***	0.64	56.49***	0.80
Shot sequence time	132.94***	0.82	645.13***	0.98	2769.94***	0.99	677.22***	0.98	236.79***	0.89	433.41***	0.97
M-VAS	149.04***	0.84	0.67	0.05	7001.58***	0.99	7.01**	0.33	286.08***	0.91	4.71*	0.25
PVT-B RT	27.50***	0.49	179.75***	0.93	957.56***	0.86	82.53***	0.86	14.73***	0.34	70.34***	0.83

Notes:
* $P < .05$.
** $P < .01$.
*** $P < .001$.

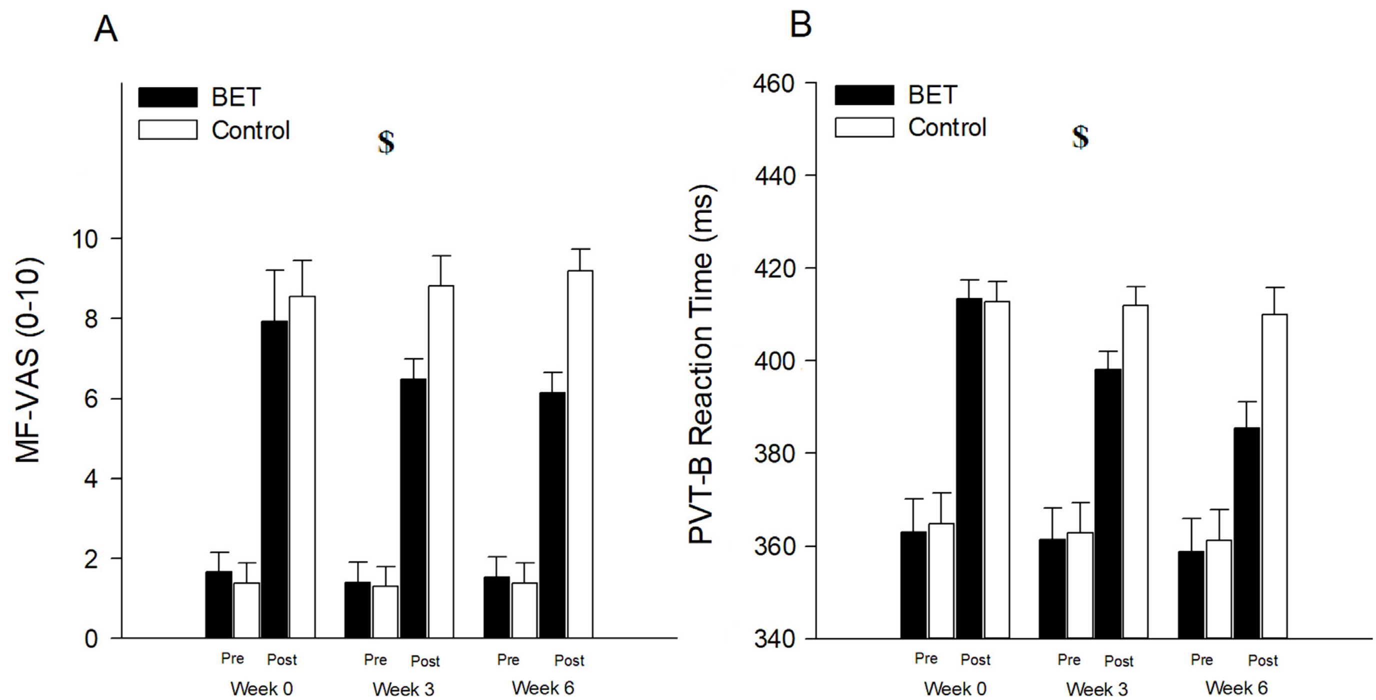

Fig. 3. Cognitive performance and subjective ratings at weeks 0, 3 and 6, pre and post Stroop task for the iBET and control groups.
(A) M-VAS reaction time across groups and time pre (before) and post (after) the Stroop task. (B) Reaction time during the brief psychomotor vigilance test (PVT-B) across groups and time, pre (before) and post (after) the Stroop task.
$Significant group × time × test. Error bars indicate standard deviation.
iBET indicates intermixed brain endurance training; M-VAS indicates mental fatigue visual analog scale; PVT, psychomotor vigilance test.

for LSPT original time and penalty time and LSST points per shot following iBET at week 6.

ANOVA on the M-VAS ratings during testing yielded a large test effect, a large group by test effect, a medium group by time effect, and a small group by time by test effect (Table 1). Fig. 3A depicts how the 30-min Stroop task elicited a profound state of mental fatigue, with M-VAS ratings increasing from just over 1 out of 10 to more than 7 out of 10, with this increase being becoming progressively smaller over time for iBET group relative to the Control group.

ANOVA on reaction times during the PVT-B produced large main and interaction effects, including the key group by time by test interaction (Table 1). Fig. 3B shows that reaction times were consistently slowed after completing the Stroop task in both groups. The extent of the slowing became relatively less pronounced for iBET relative to Control as training progressed, such that both groups did not differ at baseline testing (week 0), while the iBET group was less slowed after 3 weeks of training and least slowed after 6 weeks of training. No differences were found for the Control group progressing from week 0 to weeks 3 and 6.

All players completed 18 physical training sessions, during the 6-week training period. Group by week ANOVAs on the PVT-B responses yielded a main effect of group on reaction time, whereby the iBET group was constantly slower than the control group. A group by week effect for M-VAS showed that perceived mental fatigue at completion of the training sessions was higher in the iBET group than in the control group. No significant group main or interaction effects were found for physical RPE, confirming that the two groups experienced the same physical demands during training (Table 2). In sum, the iBET group players completed 432 min of cognitive tasks across 18 training sessions (24-min per training session). Similarly, the control group players rested for the same amount of time between exercise bouts.

4. Discussion

The objective of the present study was to determine the effects of a 6-week iBET intervention on professional soccer players' ball passing,

Table 2
Summary of the key findings from the 2 groups (iBET, Control) by 6 week (1, 2, 3, 4, 5, 6) ANOVAs on M-VAS (0–10), PVT-B RT (ms) and RPE (0–10) during training.
Note: iBET indicates intermixed brain endurance training; CON indicates control; M-VAS indicates mental fatigue visual analog scale; PVT-B RT indicates brief psychomotor vigilance test reaction time performance; and RPE indicates physical rating of perceived exertion.

Measures	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Group		Week		Group × week	
	iBET	CON	iBET	CON	iBET	CON	iBET	CON	iBET	CON	iBET	CON	F (1, 29)	η_p^2	F (5, 145)	η_p^2	F (5, 145)	η_p^2
M-VAS	7.9 (0.31)	6.1 (0.36)	8.6 (0.33)	6.4 (0.32)	9.0 (0.22)	6.3 (0.25)	9.0 (0.33)	6.6 (0.28)	9.1 (0.31)	6.7 (0.29)	8.9 (0.26)	6.5 (0.38)	185***	0.98	29.4***	0.50	8.64***	0.23
PVT-B RT	419 (22)	396 (8)	419 (21)	398 (10)	421 (19)	400 (23)	419 (23)	400 (23)	420 (22)	400 (14)	420 (22)	399 (20)	125***	0.79	3.74**	0.43	0.11	0.02
RPE	7.9 (0.31)	7.7 (0.27)	8.1 (0.42)	8.0 (0.35)	8.1 (0.26)	8.0 (0.35)	7.9 (0.37)	8.0 (0.37)	8.2 (0.45)	8.3 (0.44)	8.2 (0.33)	8.3 (0.37)	0.58	0.02	8.72***	0.23	0.85	0.02

Notes:
** $P < .01$.
*** $P < .001$.

ball shooting, and general cognition in fresh and fatigued states. As hypothesized, the findings confirmed that iBET improved soccer-specific technical skills and psychomotor vigilance performance when players were in a fatigued state compared to standard training. No performance differences between iBET and control groups were found when players were in a fresh state.

The pre-, mid-, and post-test LSST and LSPT scores showed the benefits of iBET when players were mentally fatigued. Specifically, the control group's LSST and LSPT scores were consistently lower after the Stroop task compared to before it, whereas the iBET group's performance was impacted less and less as training progressed (i.e., ball passing and shooting times as well as points scored recovered as a function of training duration). Briefly, the effect of the Stroop task was the same in weeks 0, 3, and 6 for the control group, but it was greatest in week 0 and smallest in week 6 for the iBET group. Importantly, the iBET group's passing times and points per shot did not differ from before to after the Stroop task in week 6. In contrast, the finding for the control group is consistent with evidence on the effect of mental fatigue on technical performance in soccer,[3,22] which demonstrated that mental fatigue induced by a demanding cognitive task can impair subsequent passing and shooting performance. In the present study, the pre-, mid- and post-test performance of the control group decreased from before to after the Stroop task. These data confirm that technical soccer skills are impaired by mental fatigue in professional players (current study) and amateur players (previous studies).[17] In contrast, the iBET group improved their shooting and passing skills while fatigued. At week 0, the iBET group's performance was impaired by the mental fatigue Stroop task manipulation by 5 % for passing and 10 % for shooting. However, the negative effect of mental fatigue evoked by the Stroop task on performance was attenuated by iBET at week 3 and completely nullified at week 6, when no differences were found between fresh and fatigued states. These findings provide further support for the hypothesis that iBET develops resistance to mental fatigue[12,13,15] and thereby improves players' performance under mentally fatiguing conditions. Earlier BET studies on endurance,[12] sprinting,[13] and padel[15] performance demonstrated this effect. Specifically, the present findings are consistent with those of Diaz and colleagues,[15] who also used an iBET protocol and demonstrated its efficacy for padel shot performance subsequent to a mentally fatiguing Stroop task. In agreement with this demonstration, our results confirmed a similar pattern whereby iBET first attenuated and later completely mitigated the negative effect of mental fatigue (caused by a cognitively demanding task). However, both this and the previous iBET study did not observe any difference in performance between groups when fresh. Although this is the first study to investigate the effect of iBET on technical performance in soccer players, the findings are consistent with those of a previous study[15] which found that BET did not affect padel shot speed and accuracy when players were rested and feeling fresh. The present finding for fresh state performance contrasts with a previous BET study in professional soccer players which found that BET improved multitasking performance when fresh.[13] It is worth noting that the previous study used a *post* BET protocol (compared to the present study's *intermixed* BET protocol) and it assessed multitasking performance in a high intensity physical task (compared to the present study's low intensity passing and shooting tasks).

Previous studies have shown that mental fatigue impairs technical soccer skills, such as passing and shooting[3,7] and general motor skills. It has been speculated that BET enhances sport performance via adaptations to specific frontal brain regions, such as the anterior cingulate cortex, which are engaged during cognitive activities similar to those performed during iBET.[23] This is relevant given the involvement of frontal brain regions in mental fatigue and effort tasks.[23,24] It is possible that brain adaptations[11,16] raised the threshold at which physical performance decreases due to fatigue or increased resilience to execute movements (e.g., passing or shooting) when fatigued.

It remains to be determined whether iBET directly improved shooting and passing skills in fatigued conditions or whether it indirectly acted by improving the football players' ability to successfully complete the Stroop response inhibition task and thereby evoke less mental fatigue (confirmed by the MF-VAS ratings) prior to completing the second (fatigued) round of shooting and passing tests. Nonetheless, at post-testing, the M-VAS scores of the iBET group were still higher after completing the Stroop task compared to when they were fresh, supporting the hypothesis that this form of combined training enhances players' ability to deal with mental fatigue. As a result, the iBET group's ability to perform may have improved with training despite poor performance monitoring, focusing, and goal-directed attention, all of which are affected by mental fatigue[3,22] and are aggravated in match situations.[25]

We measured the psychomotor vigilance of the players during testing both before (fresh state) and after (fatigued state) a demanding cognitive task, namely, the incongruent Stroop task. The slowing of reaction times during the psychomotor vigilance task from before to after the Stroop task in all testing sessions is in line with previous studies[14,26] showing that mental fatigue slows cognition. Furthermore, the finding that players' reaction times tested in optimal settings (i.e., fresh state) was not improved by iBET shows that simple non-executive function cognitive task (e.g., PVT-B) performance was not improved by iBET. These results are in line with the previous BET study on soccer[13] and other studies in young healthy adults which reported no improvements when tested in a fresh state.[27] Nevertheless, our findings indicate that iBET hastened PVT-B reaction times, indicative of greater vigilance and readiness to perform, when players were mentally fatigued. The results indicate that iBET improved reaction time by 7 % at post-test compared to pre-test, whereas the control group did not improve. Therefore, iBET enhanced the players' capacity to remain vigilant even when experiencing fatigue following a cognitive task. These findings are consistent with earlier BET research on the effects of cognitive and/or physical demanding tasks on cognitive performance in fatigued conditions.[12,13,15] Importantly, the considerably improved PVT-B performance was accompanied by decreased subjective mental fatigue in the BET group. One potential explanation is that the iBET group exhibited greater resilience toward mental fatigue when engaging in the Stroop task, resulting in faster performance on the subsequent PVT-B compared to the control group. Indeed, prior research has demonstrated that BET improved performance on 30-min Stroop tasks while also reducing the perceived cognitive load associated with the Stroop task.[12,13] The faster response time that characterized the iBET group suggests greater resilience toward mental fatigue.[12,13] Such resilience durability and enhanced cognitive capacity can be expected to improve the performance of soccer teams under conditions of increased fatigue and weariness (i.e. end of the second half of a match), which could manifest as conceding fewer goals during competitive matches.[28,29]

We incorporated 24 min of cognitively demanding tasks into standard physical training sessions. This iBET protocol increased subjective mental fatigue during training by 29 % compared with the control group that performed physical training alone. Moreover, during training assessment, we found that performance on the PVT-B, a behavioral marker of mental fatigue, was 45 % worse for iBET than control players. These findings are broadly consistent with those of previous BET studies[12,13,15] and show that iBET increases the cognitive load of physical training. The finding that the physical load was the same for the iBET and control groups, as indicated by their RPE, is crucial for interpreting the study findings. Consequently, the observed differences in performance outcomes at the end of the training period can be attributed to the additional cognitive burden associated with increased cognitive load due to iBET rather than physical load. Similar to a previous BET study in soccer,[13] this increased cognitive load was created by the addition of 24 min of cognitive tasks to the exercise training tasks.

The present study has made novel discoveries that can be incorporated into the training regimens of athletes. Nevertheless, it is important to consider potential limitations when evaluating the findings. First, the sample size was relatively small. The recruitment of participants was constrained by the available squad size and the study's inclusion/exclusion criteria, including injury considerations. Although research has demonstrated that a similar sample size, ranging from 24 to 30, players is sufficient to detect statistically significant effects of BET for cognitive and physical performance, future studies could broaden their recruitment strategy to encompass multiple clubs. This approach would increase the overall sample size and strengthen the evidence concerning the effectiveness of iBET in professional soccer players. Second, the control group was passive. Players engaged in standard physical training and recovery. A more active control group could help to exclude the potential confound that the benefits of iBET may have been influenced, to some extent, by engaging in supplementary training activities, such as cognitive exercises, in addition to standard training. Third, a state of mental fatigue was only corroborated by subjective and behavioral markers during testing. Physiological markers could help triangulate these markers and control for potential confounders, such as heart rate and heart rate variability. Similarly, our characterization of the physical training load relied on subjective and behavioral markers. Studies may include additional physiological assessments and global positioning satellite assessment records to more accurately monitor external load. Fourth, due to a malfunction of the radar used to measure shot speed, we were unable to score these data. However, players were unaware of this equipment malfunction and the radar was set up in the field during testing. Accordingly, players were encouraged to shoot as fast as possible during the tests. Finally, future investigations could collect neurophysiological measures to identify the specific brain mechanism(s), such as changes in activation of specific brain regions, responsible for the observed iBET-related enhancements in soccer performance.

5. Conclusions

The current study presents evidence confirming that BET improves professional soccer players' soccer-specific technical skills of passing and shooting. Moreover, this study demonstrates that BET improves psychomotor vigilance and inhibitory control in cognitively demanding situations that elicit mental fatigue. The study shows that iBET is an effective method for reducing the negative impact of mental fatigue on performance[30] and highlights the key role played by cognitive operations in athletic performance. Further investigation is warranted to establish the impact and underlying processes of iBET, considering the importance of technical skill execution and fatigue resistance among professional athletes participating in team sports.

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Confirmation of ethical compliance

The study was approved by the Ethics Committee for the University of Extremadura in accordance with the Declaration of Helsinki.

CRediT authorship contribution statement

Walter Staiano: Methodology, Validation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Jesús Díaz-García:** Conceptualization, Methodology, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Funding acquisition. **Tomás García-Calvo:** Software, Investigation, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Christopher Ring:** Conceptualization, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Supervision.

Declaration of interest statement

We declare that any author in the present study does not have any conflict or personal interest related to the data collected.

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