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Brain Endurance Training Improves and Maintains Chest Press and Squat Jump Performance When Fatigued

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[1]Faculty of Sport Sciences, University of Extremadura, Cáceres, Spain; [2]Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimiento Humano, University of Évora, Évora, Portugal; [3]Comprehensive Health Research Centre (CHRC), University of Évora, Évora, Portugal; and [4]School of Sport, Exercise & Rehabilitation Sciences, University of Birmingham, Birmingham, United Kingdom

Abstract

Díaz-García, J, López-Gajardo, MÁ, Parraca, JA, Batalla, N, López-Rodríguez, R, and Ring, C. Brain endurance training improves and maintains chest press and squat jump performance when fatigued. *J Strength Cond Res* XX(X): 000–000, 2024—Mental fatigue can impair resistance exercise performance. Brain endurance training (BET)—the addition of demanding cognitive tasks to standard exercise training—improves endurance exercise performance more than standard training. Although BET has yet to be evaluated with resistance exercise, it is expected to improve performance, particularly when the performer feels mentally fatigued. The study employed a pretest (week 0), midtest (week 3), posttest (week 6), and follow-up (week 9) design, with subjects randomized to BET ($n = 46$) or control (exercise training) ($n = 45$) groups. In testing sessions, subjects performed chest press and squat jump exercises to failure before (feeling fresh) and after (feeling tired) a 30-minute cognitively demanding Stroop task. Training comprised 5 BET or control training sessions per week for 6 weeks. In each training session, subjects completed 4 sets of each exercise to failure, with each exercise set preceded by a 3-minute cognitive task (BET) or rest (control). Exercise performance (number of repetitions to failure) and mental fatigue markers were assessed. In pretesting, exercise performance did not differ between the groups. In midtesting and posttesting, BET performed more chest press and squat jump repetitions when fatigued by the 30-minute Stroop than control. The mental fatigue elicited by the Stroop task gradually declined with training in BET compared with control. In conclusion, BET enhanced resistance exercise performance compared with standard training when tested subsequent to a mentally fatiguing cognitive task. These benefits were maintained weeks after training ended. Brain endurance training is an effective method to mitigate the deleterious effects of mental fatigue on resistance exercise performance.

Key Words: mental fatigue durability, repetitions to failure, resistance exercise

Introduction

Mental fatigue, defined as a psychobiological state induced by prolonged and demanding cognitive demands, can impair athletes' exercise (31) and psychomotor (18) performance. Although the mechanisms underlying the mental fatigue-performance relationship have yet to be established, the putative candidates include prefrontal cortical processes, effort, motivation, and resource depletion (8,19,20,24). Mental fatigue in athletes is associated with sport participation (31), travel (30) and sleep deprivation (13), and smartphone use (14,15). The manifestations of mental fatigue include subjective (e.g., lack of energy) (27), behavioral (e.g., impaired response speed and accuracy) (26), and physiological (e.g., changes in heart rate variability and electroencephalographic activity) (16,17) responses.

It is well established that mental fatigue impairs aerobic endurance exercise performance (31). This performance impairment has been attributed to greater perceived effort during states of elevated mental fatigue in the absence of cardiorespiratory and metabolic changes (22). By contrast, mental fatigue does seem to not impair maximal anaerobic exercise performance, such as maximum contractions and efforts (5). It has been suggested that this lack of impairment in the case of maximal performance is because cognitive resources are not relevant for these types of exercise (1). Finally, studies examining the effects of mental fatigue on resistance exercise performance are limited in number and mixed in outcome (1,5). Notably, several recent studies report reductions in leg contraction duration (3) and number of bench press and half-back squat repetitions to failure (2,9,23) when mentally fatigued by a 30-minute cognitive Stroop task. Importantly, these recent findings agree with the meta-analytic review of earlier studies that revealed that mental fatigue impairs both upper-body and lower-body resistance exercise performance (1). Grounded on this evidence, this study explored the effect of mental fatigue on resistance exercise performance and its mitigation by a training-based countermeasure.

Given the abovementioned evidence showing that mental fatigue can impair sport and exercise performance, researchers have come up with countermeasures to help athletes mitigate the problem (25). In terms of short-term countermeasures, the

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strongest evidence supports the use of caffeine, music, and motivational self-talk. In terms of long-term countermeasures, brain endurance training (BET)—the combination of cognitive and physical training—is a viable option for athletes wishing to develop adaptations and resilience against mental fatigue (28,29). Based on Marcora's *psychobiological model* of endurance exercise, BET requires athletes to complete cognitively demanding tasks alongside their standard exercise training tasks to subsequently enhance exercise performance by making exercise feel easier (23). The effectiveness of BET to improve subsequent endurance exercise has been demonstrated in several published studies, including those that used handgrip tasks (7,8).

This study explored fresh and fatigued resistance exercise performance before, during, and after training with standard exercise training (control) versus combined exercise and cognitive training (BET). Gym-based resistance exercises are a standard feature of many athletes' strength and conditioning programs. Given that such training can be negatively affected when athletes are in a state of mental fatigue (1,5), strength and conditioning coaches may be interested in seeing whether a training-based countermeasure can help them adapt to the demands of harder training and subsequently develop mental fatigue resilience and reduced perceived effort. Our study purposes were fourfold. Our first study purpose was to determine the effect of fatigue, elicited by completing prior exercise and cognitive tasks, on subsequent resistance exercise performance. We hypothesized that subjects would complete fewer exercise repetitions to failure when fatigued than when fresh. Our second study purpose was to determine the effects of BET on resistance exercise performance. We hypothesized that subjects would complete more resistance exercise repetitions to failure following BET than standard training (control). Our third study purpose was to determine the effects of exercise and cognitive tasks on subjective, behavioral, and physiological indices of mental fatigue. We hypothesized that subjects would give higher ratings, display slower reaction times, and exhibit lower heart rate variability after than before the tasks. Our fourth study purpose was to evaluate the impact of BET on task-related changes in mental fatigue. We hypothesized that subjects would experience less mental fatigue following BET than control.

Methods

Experimental Approach to the Problem

The study employed a pretest-training-midtest-training-posttest order followed by standard training and retention test design (see Figure 1), with subjects randomly allocated to BET (n = 46) or control (n = 45) groups. During the intervention, subjects completed 5 training sessions per week for 6 weeks. In each training session, all subjects performed the same chest press and squat jump exercise tasks; however, during the short breaks between exercise tasks, the BET group performed a cognitive (Stroop) task, whereas the control group rested. Subjects were tested in week 0, at the end of week 3, and at the end of week 6. Finally, to evaluate retention of BET effects, all subjects performed standard (i.e., control) training for 3 weeks (5 sessions per week) before being retested at the end of week 9 (i.e., follow-up). In each testing session, subjects performed chest press and squat jump exercises to failure when fresh and when fatigued by a 30-minute Stroop task. The numbers of repetitions of the chest press and squat jump served as the measures of strength endurance exercise performance. The degree of mental fatigue was assessed before (i.e., when feeling fresh) and after (i.e., when feeling tired) the Stroop task using subjective (rating using visual analog scale-Mental Fatigue, VAS-MF), behavioral (reaction times on a psychomotor vigilance task), and physiological (heart rate variability) markers.

Subjects

Ninety-one (49 men and 42 women) resistance-trained athletes were recruited and gave informed consent to participate. Their (mean [*SD*] age was 29.42 [10.06] {range 21–37} years, height was 182.55 [10.91] cm, and mass was 81.17 [7.35] kg). They had a minimum of 1 year of resistance training experience, currently trained 5 times per week, and regularly performed the bench press and squat jump exercises. They discontinued their normal training regimens during the study. The protocol was approved by the Ethics Committee at the University of Extremadura, Spain, in accordance with the Declaration of Helsinki (study protocol 93/2020). Subjects were naive to our study purposes and hypotheses. None dropped out. Power calculations using GPower software (12) indicated that with a sample size of 91, our study was powered at 80% to detect significant ($p < 0.05$) between-within interaction effects ($f = 0.13$, $\eta_p^2 = 0.02$) corresponding to a small effect size by analysis of variance (6).

Measures. Subjective, behavioral, and physiological markers of mental fatigue were obtained. Using the VAS-MF, subjects were asked "*How mentally fatigued do you feel*?" and responded by placing a mark on a 10-cm line, anchored by "not at all" and "maximum level of mental fatigue possible." This scale is sensitive to changes in mental fatigue among athletes (26). Players also completed a 3-minute Brief Psychomotor Vigilance Task (PVT-B) to assess mental alertness and readiness to perform. They were presented a visual stimulus, with a 1–4 second interstimulus interval, in the centre of a smartphone, and were required to respond by pressing the touchscreen as fast as possible; reaction time was recorded (11). Heart rate variability, assessed using the root mean square of successive differences (RMSSD, ms), was also obtained from the R-R intervals recorded by a Polar RS800CX heart rate strap and monitor. Previous studies have documented effects of mental fatigue on this marker (10,16,17).

Tasks. The chest press is an upper-body (pectoral, deltoid, and triceps muscles) exercise: the subject laid on their back and kept their upper arms perpendicular to their body and their forearms perpendicular to the floor. At the start, the subject slowly pushed the bar or weights upwards until their elbows were almost straight and they felt tension in their upper chest (see Supplemental Digital Content 1, http://links.lww.com/JSCR/A500). The squat jump is a lower-body (quadriceps, glutes, and hamstring muscles) exercise: the subject stood with their feet shoulder width apart and knees slightly bent, flexed their knees, descended into a squat position, jumped off the ground, and extended their legs (see Supplemental Digital Content 1, http://links.lww.com/JSCR/A500). They watched instructional videos, read written instructions, and were given tips about technique for each exercise.

The incongruent Stroop task is a response inhibition task that elicits mental fatigue. In this incongruent Stroop test, a word representing 1 of 4 colors (blue, green, red, yellow) was displayed on a 69 × 55-cm monitor in a different color on a black background, and subjects were instructed to press a button to indicate the meaning of the words as quickly and accurately as possible. All words were displayed in a different color to their meaning

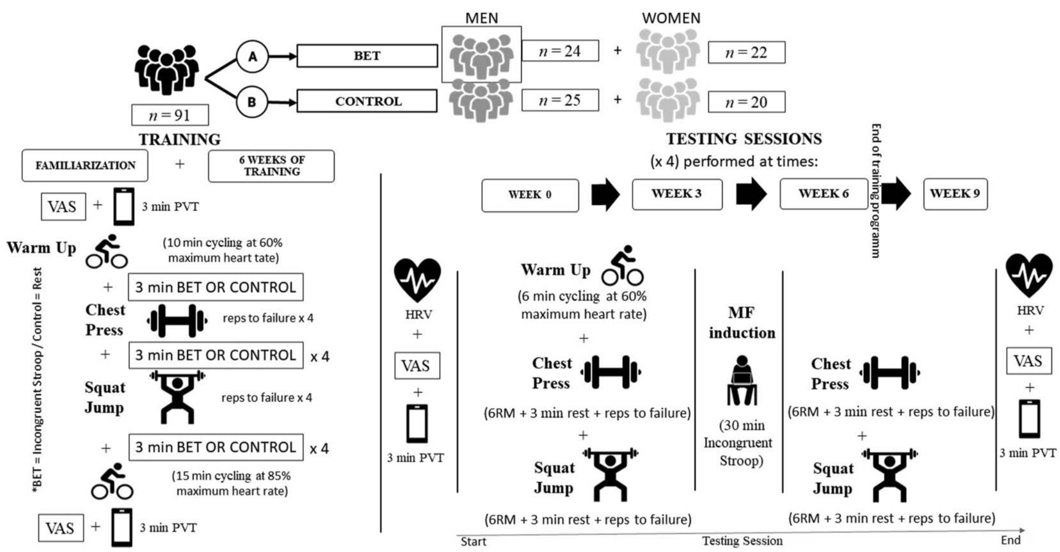

Figure 1. Study training and testing protocol. Notes: BET = brain endurance training; HRV = heart rate variability; PVT = brief psychomotor vigilance task; reps = repetitions; VAS = visual analog scale-mental fatigue; 6RM = 6 repetition maximum.

(i.e., 100% incongruent trials). The interstimulus interval was 1900 ms. A researcher sat behind the subject to ensure compliance.

Procedures

Testing. Subjects completed 4 testing sessions at weeks 0, 3, 6, and 9 (see Figure 1). Markers of mental fatigue were obtained at the start and end of each session. After warming up by cycling at 60% of maximum heart rate (i.e., 220—age) for 6 minutes, they performed the following sequence: determine chest press 6RM, 3-minute rest, chest press repetitions to failure at 40% 6RM, 3-minute rest, squat jump repetitions to failure, 30-minute Stroop task, chest press repetitions to failure at 40% 6RM, 3-minute rest, and squat jump repetitions to failure. Testing took place at the same time of day. Before sessions, subjects were encouraged to sleep at least 7 hours the previous night, refrain from caffeine and alcohol for 12 hours, refrain from vigorous physical activity for 24 hours, and avoid creatine.

Training. Subjects completed 5 training sessions per week for 6 weeks (see Figure 1). Sessions were supervised by a professional certified strength and conditioning coach. At the start of each session, they warmed up for 10 minutes by cycling at 60% of maximum predicted heart rate. Next, they performed 4 sets of chest press exercise at 40% 6RM to failure and 4 sets of squat jump exercise to failure. During the 3-minute recovery after the warm-up cycling exercise and between the exercise sets, the BET group performed an incongruent Stroop task (i.e., 9 × 3-minutes = 27 minutes of cognitive tasks), whereas the control group rested. At the end of each session, they warmed down for 15 minutes by cycling at 85% of maximum predicted heart rate.

Our rationale for choosing to train these 2 exercises was twofold. First, bench press and squat jump are 2 of the most commonly studied upper-body and lower-body exercises in the scientific literature. Indeed, their benefits for health and performance (e.g., squat training is associated with improved jumping performance) are well established. Second, the basic motor control aspects for both exercises will have already been

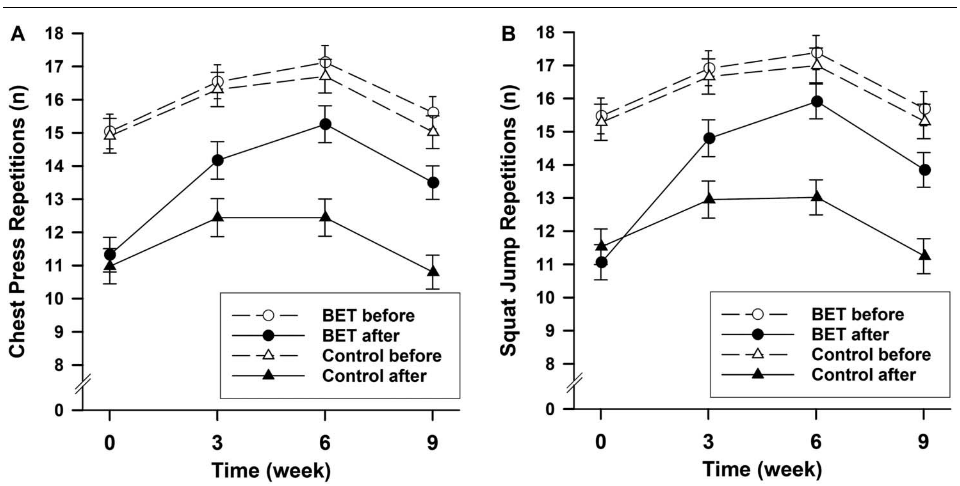

Figure 2. Mean (*SE*) number of repetitions to failure of the chest press and squat jump exercises as a function of group (BET, control), time (0, 3, 6, 9 weeks), and test (before Stroop, after stroop).

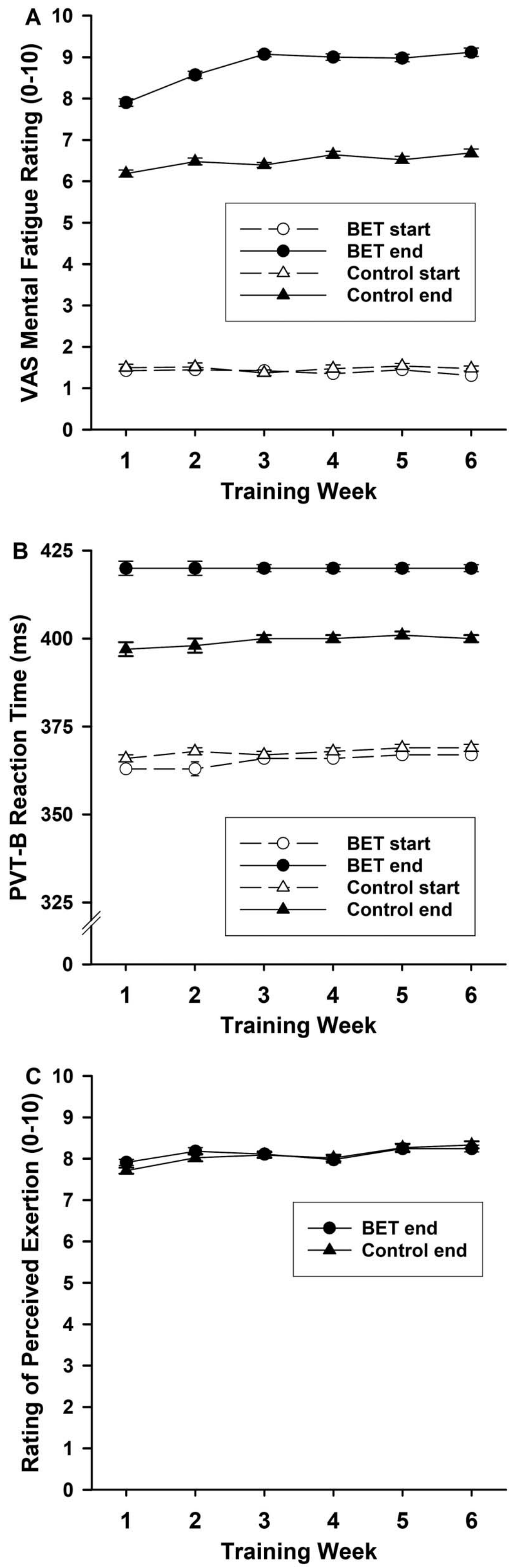

Figure 3. Mean (*SE*) VAS mental fatigue rating, PVT-B reaction time, and RMSSD as a function of group (BET, control), time (0, 3, 6, 9 weeks) and test (before stroop, after stroop).

acquired in our sample of experienced athletes. Accordingly, any BET-related improvements in the number of repetitions until failure are more likely to be attributed to advanced central changes rather than simple peripheral technique changes seen during the acquisition phase of learning to execute any movement.

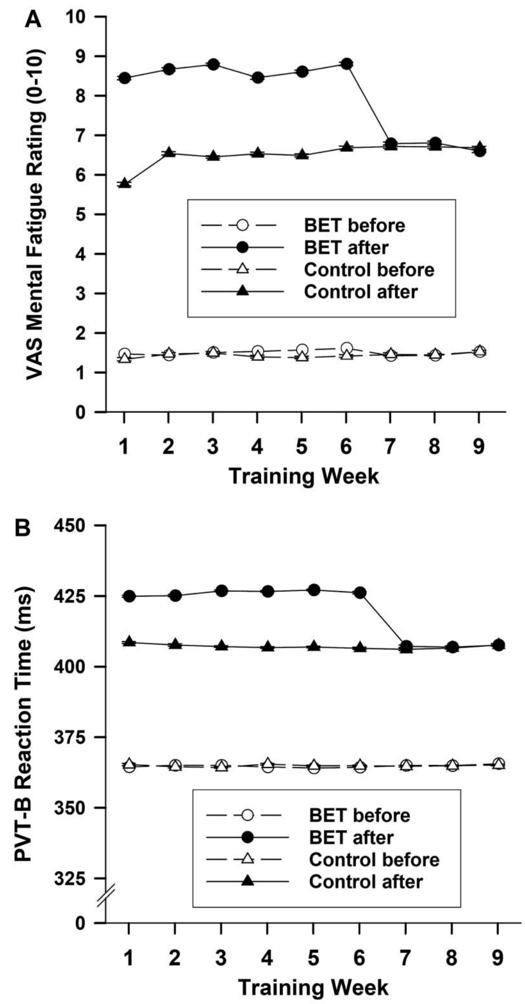

Figure 4. Mean (*SE*) VAS mental fatigue rating and PVT-B reaction time as a function of group (BET, control), week (1, 2, 3, 4, 5, 6, 7, 8, 9) and training session (before, after) during the 6-weeks of the intervention and the subsequent 3 weeks of standard training.

Statistical Analyses

A series of mixed factorial ANOVAs, with group (BET, control) as the between-subject factor, and with time (0, 3, 6, 9 weeks) and test (before Stroop, after Stroop) as the within-subject factors, were performed on the number of repetitions to failure and markers of mental fatigue during testing. A series of mixed factorial ANOVAs, with group (BET, control) as the between-subject factor, and with week (1, 2, 3, 4, 5, 6, 7, 8, 9), day (1, 2, 3, 4, 5), and training (before, after) as the within-subject factors, were performed on the markers of mental fatigue during training. Partial eta-squared (η_p^2) was reported as a measure of effect size, with values of 0.02, 0.13, and 0.26 indicating small, medium, and large effect sizes, respectively (6). Significance was set at $p < 0.05$. Analyses were conducted using the Statistical Package for the Social Sciences (SPSS 29) software (IBM).

Results

Resistance Exercise Performance

A series of 2 group (BET, control) by 4 time (0, 3, 6, 9 weeks) by 2 test (before Stroop, after Stroop) ANOVAs on the number of repetitions to failure yielded large main effects for time and test as well as large interaction effects for group by time, group by test, and group by time by test for both chest press and squat jump exercises (see Figure 2 and Table 1). Subjects performed progressively more repetitions as a function of weeks of training; steadily increasing from week 0 to week 3 and from week 3 to week 6. Performance declined in week 9 relative to week 6 (when cognitive training ended). They also consistently performed fewer repetitions after the 30-minutes of Stroop task than they performed before the 30-minutes of Stroop task. Importantly, large group by time by test interaction effects were found for each resistance exercise. In both cases, the number of repetitions was consistently and similarly lower after than before the Stroop task in the control group, whereas exercise repetitions were reduced less and less by the Stroop task as training progressed for the BET group. In brief, the impact of the Stroop task was equally large at every test session (i.e., weeks 0, 3, 6 and 9) for the control group but was maximal at week 0 and minimal at week 6 for BET.

Mental Fatigue

The mental fatigue markers during testing are displayed in Figure 3, and the accompanying 2 group by 4 time by 2 test ANOVAs are summarized in Table 1. These ANOVAs on VAS-MF mental fatigue ratings, PVT-B reaction times, and RMSSD produced large effects for time, test, group by time, group by test, and group by time by test. The Stroop task induced a state of mental fatigue, with VAS-MF ratings increasing from 1 to 8 out of 10, with this increase being consistent across weeks for the BET group but gradually greater across weeks for the control group. Reaction times during the PVT-B, a task sensitive to alertness and readiness to perform, were slowed after completing the Stroop task in both groups, with the extent of the slowing becoming relatively smaller in the BET group compared with the control group as training progressed, such that the BET group were slowed most at 0 weeks (baseline), slowed less at 3 weeks, and slowed least at 6 weeks (end of training) and 9 weeks (follow-up). Root mean square of successive differences, a measure of heart rate variability, was lower after completing the Stroop task in both groups, with the extent of the lowering substantial and consistent in the control group as training progressed, whereas the lowering gradually recovered as training progressed in the BET group, such that their RMSSD was lowered most at 0 weeks, less at 3 weeks, and least at 6 and 9 weeks. Taken together, these markers confirmed that the Stroop task always induced a profound state of mental fatigue, with the extent of mental fatigue gradually becoming less and less in the BET group but staying consistent in the control group.

Training

The mental fatigue markers during the training sessions are presented in Figure 4. The 2 group (BET, control) by 9 weeks (1, 2, 3, 4, 5, 6, 7, 8, 9) by 5 days (1, 2, 3, 4, 5) by 2 training (before, after) ANOVAs yielded large effect sizes for group, training, and group by training for VAS-MF ratings and PVT-B reaction times (Table 2). Training increased VAS-MF ratings and slowed PVT-B reaction times in both groups. Importantly, before training, the 2 groups exhibited similar levels of mental fatigue; however, after training, the BET group gave higher VAS-MF ratings and responded slower during the PVT-B than the control group during the 6 weeks of the intervention but not during the subsequent 3 weeks. Taken together, these data confirm that the cognitive load while training during the intervention was more mentally fatiguing for BET than for control.

Discussion

We examined the effects of BET on the performance of resistance exercises when fresh and fatigued (by previous sets of resistance exercises and a lengthy cognitive task). The main study findings indicated that a state of fatigue elicited by the Stroop response inhibition task reduced the numbers of chest press and squat jump exercise repetitions to failure, and, importantly, that BET improved the number of exercise repetitions when fatigued compared with standard training. A state of elevated mental fatigue was confirmed by increased subjective ratings of mental fatigue, slower reaction times during a brief vigilance task, and lower heart rate variability during the testing sessions. Over the 6 weeks of the combined training intervention, the exercise and cognitive tasks elicited progressively less impact on the subjective, behavioral, and physiological markers of mental fatigue in the BET group but not the control group. These BET-related changes in performance and fatigue resistance persisted at follow-up, 3 weeks after the end of additional cognitive training. Taken together, these findings confirm that fatigue-related impairments in resistance exercise performance were mitigated by BET and that this mitigation was maintained, at least in part, after BET. The key findings are discussed below in relation to our study purposes.

Our first study purpose was to determine the effect of being in a state of fatigue, experienced after completing prior exercise and cognitive tasks, on subsequent resistance exercise performance. In support of our hypothesis, we found that subjects completed

Table 1

Summary of the 2 group (BET, control) by 4 time (0, 3, 6, 9 weeks) by 2 test (before stroop, after stroop) ANOVAs, including the effect size η_p^2, on exercise performance and mental fatigue indices.*†

	Group		Time		Test		Group × time		Group × test		Time × test		Group × time × test	
Measures	F (1, 89)	η_p^2	F (3, 87)	η_p^2	F (1, 89)	η_p^2	F (3, 87)	η_p^2	F (1, 89)	η_p^2	F (3, 87)	η_p^2	F (3, 87)	η_p^2
Chest press repetitions (n)	2.43	0.03	241.03***	0.89	694.01***	0.89	20.04***	0.41	38.71***	0.30	11.18***	0.28	19.64***	0.40
Squat jump repetitions (n)	1.91	0.02	407.28***	0.93	1,040.55***	0.92	44.04***	0.34	51.90***	0.37	63.06***	0.69	80.69***	0.74
VAS-MF ratings (0–10)	10.94***	0.11	22.41***	0.44	21,175.80***	0.99	9.13***	0.24	13.93***	0.14	7.97***	0.22	6.37***	0.18
PVT-B reaction time (ms)	25.32***	0.22	64.23***	0.69	1,360.51***	0.94	66.18***	0.70	22.70***	0.20	34.62***	0.54	45.44***	0.61
RMSSD (ms)	143.90***	0.62	253.78***	0.90	18,624.19***	0.99	196.73***	0.87	64.13***	0.42	193.64***	0.87	225.94***	0.89

*PVT-B = Brief Psychomotor Vigilance Task; RMSSD = root mean square of successive differences; VAS-MF = Visual Analog Scale-Mental Fatigue.
†***$p < 0.001$.

Table 2

Summary of the 2 group (BET, control) by 9 week (1, 2, 3, 4, 5, 6, 7, 8, 9) [by 5 day (1, 2, 3, 4, 5)] by 2 training (before, after) ANOVAs, including the effect size η_p^2, on mental fatigue indices during the training sessions.*†

	Group		Week		Training		Group × week		Group × training		Week × training		Group × week × training	
Measures	F (1, 89)	η_p^2	F (8, 82)	η_p^2	F (1, 89)	η_p^2	F (8, 82)	η_p^2	F (1, 89)	η_p^2	F (8, 82)	η_p^2	F (8, 82)	η_p^2
VAS-MF ratings (0–10)	2,305.52***	0.96	139.21***	0.93	210,850.01***	0.99	215.75***	0.96	3,192.32***	0.97	154.77***	0.94	191.15***	0.95
PVT-B reaction time (ms)	1,346.49***	0.94	147.30***	0.94	127,859.20***	0.99	133.46***	0.93	2,231.63***	0.96	192.78***	0.95	174.59***	0.95

*BET = brain endurance training; PVT-B = Brief Psychomotor Vigilance Task; VAS-MF = Visual Analog Scale-Mental Fatigue.
†***$p < 0.001$.

fewer repetitions to failure of chest press and squat jump exercises when fatigued (after the Stroop task) than when fresh (before the Stroop task). These findings are compatible with meta-analyses showing that resistance exercise is worse when performed in a state of mental fatigue, elicited by a demanding cognitive task, such as the Stroop task, than when performed in a relatively fresh state (1,5).

Our second study purpose was to determine the effects of BET on resistance exercise performance. In support of our hypothesis, we found that BET subjects completed more resistance exercise repetitions to failure when fatigued (i.e., after Stroop task) than control subjects at every testing session apart from the baseline (week 0) pretesting session. In other words, compared with the control group, the BET group completed more repetitions of both chest press and squat jump exercises after 3 weeks of training, after 6 weeks of training, and 3 weeks after the end of cognitive training (i.e., at 9 weeks). Relative to week 0, the changes in fatigued performance at weeks 3, 6, and 9 (see Figure 2A) were 25, 35, and 19% for chest presses and 34, 44, and 25% for squat jumps in the BET group, whereas the corresponding changes were 13%, 13%, and −2% (chest presses) and 12%, 13%, and −3% (squat jumps) in the control group. These data indicate that both groups adapted and performed better when fatigued, and, importantly, that the BET group coped better than the control group while actively training (3 weeks), immediately after completing training (6 weeks), and when followed-up after the end of training (9 weeks). These BET-related performance benefits were broadly similar for both chest press exercise and squat jump exercise, both in terms of temporal profile and extent, with both peaking at 6 weeks by 35 and 44%, respectively. In sum, the ability of the control group to perform upper-body and lower-body resistance exercise was always and similarly impaired in a fatigue state compared with a fresh state, whereas that of the BET group was progressively less impaired by fatigue as a function of training with partial retention of this fatigue resistance several weeks after completing combined cognitive plus exercise training.

Contrary to our hypothesis, BET and control subjects completed similar numbers of resistance exercise repetitions to failure when fresh (i.e., before Stroop task) at every testing session. Relative to week 0, the changes in fresh performance at weeks 3, 6, and 9 (see Figure 2B) in the BET group were 10, 14, and 4% for chest presses and 9, 12, and 1% for squat jumps, whereas in the control group, the corresponding changes were 9, 12, and 1% (chest presses) and 9, 11, and 0% (squat jumps). These data show that resistance exercise performance improved with training (when tested after 3 and 6 weeks) in both groups and that their performance at follow-up (3 weeks posttraining) declined slightly while remaining above pretraining levels.

This study is the first to prove the effects of BET in the context of resistance exercise. Therefore, our finding that BET improves the ability to complete chest press and squat jump resistance exercises to failure when fatigued must await replication. Nonetheless, our positive findings are compatible with those of 2 previous BET studies showing that BET increased the cumulative amount of force produced during a 5-minute bout of rhythmic handgrip exercise, when performed subsequent to and concurrent with a demanding cognitive exercise (i.e., in a fatigued state), compared with standard physical training (7,8). It should be noted that these 2 studies also found that BET improved cumulative force production when in a fresh state, which is different to the findings of this study. Other BET studies have found that cycling (4,29) and running (28) endurance exercise are improved by BET compared with control (standard training). The article with the 2 cycling studies (29) shows that the second, but not the first, of 2 time to exhaustion and time trial tests were improved by BET. These observations, which are broadly compatible with the current observations showing that second bouts but not the first bouts of exercise are improved by BET, suggest that BET may be more likely to improve performance when athletes are tired but may be less likely when they are feeling fresh. The implication is that BET could be used strategically to aid late but not early performance in competitive sport, which is a time when fatigue has developed and performance begins to drop off. This suggestion awaits examination.

Our third study purpose was to determine the effects of exercise and cognitive tasks on subjective, behavioral, and physiological markers of mental fatigue. In line with expectations, we observed that subjects gave higher VAS-MF ratings indicative of feelings of tiredness and exhaustion, displayed slower reaction times during the PVT-B indicative of reduced alertness and preparedness to respond, and exhibited lower RMSSD scores (i.e., reduced heart rate variability) indicative of disturbed autonomic balance, after the tasks compared with before the tasks (Figure 3). These findings are compatible with a large body of evidence showing that completing demanding exercise or cognitive tasks, including sports, can increase mental fatigue in athletes.

Our fourth study purpose was to evaluate the impact of BET on task-related changes in mental fatigue. In relation to our hypothesis, we found supporting evidence that reaction times slowed less and heart rate variability fell less after the Stroop task in BET subjects than in controls, but we also found contrary evidence that the VAS ratings were similarly elevated in both groups. These data suggest that BET helped subjects better tolerate the effects of prior exercise and cognitive tasks. Specifically, BET mitigated the size of the changes in the behavioral and physiological mental fatigue markers (but not the subjective marker) from before to after the Stroop task during testing. These findings are compatible with the view that BET helps increase resistance to the contextual sources of mental fatigue. Such mental fatigue resistance with BET adds to evidence that it represents a long-term behavioral countermeasure that athletes could readily incorporate into their standard training programs to help inoculate them against the deleterious negative effects of mental fatigue on performance.

This study highlights the benefits of BET on resistance exercise performance when mentally fatigued. Nonetheless, potential study limitations should be considered when interpreting the findings. First, the study focused on regular gym goers. Therefore, our findings may not fully generalize to professional weightlifters and bodybuilders, whose training experiences may make them be less susceptible to mental fatigue. Future studies should evaluate the effects of BET on resistance exercise in relation to weight training experience. Second, we only examined 2 exercises, chest press and squat jump. It is likely that the effects of mental fatigue, and therefore, BET will vary among different types of exercise. Such variations could be explored in programmatic research plans. Third, we did not collect biomechanical and physiological measures, such as movement kinematics, muscle activation patterns, and cortical oscillations, to gain an understanding of potential mechanisms that mediate BET-related improvements in exercise performance. Therefore, mechanistic studies could replicate and extend the present findings and include a variety of measures to help identify the peripheral and/or central mechanism(s) underpinning the improved resistance exercise performance observed here.

This study provides the first evidence that BET improves resistance exercise performance, with recreational athletes able to complete more repetitions to failure when in a fatigued state. It also demonstrates that this benefit persists for several weeks after the end of the additional cognitive training. These novel pieces of evidence add to those from past research showing that BET improves endurance performance in various endurance exercise tasks, including rhythmic handgrip as well as cycling and running. We have shown here how the cognitively demanding elements of a BET training protocol can be easily completed between exercises (or sets) by replacing rests with short-lasting cognitive tasks. Such an intermixed BET protocol is time efficient and therefore more attractive to busy athletes. The cognitive tasks and scheduling regimes can be optimized in future studies. Such investigations can also help to identify the underlying psychobiological mechanism(s) that are responsible for BET-related improvements in resistance exercise performance.

Practical Applications

Our study findings should help strength and conditioning coaches to improve their understanding of the mental side of resistance training and thereby help their clients practice and perform better. These coaches have already increased their understanding of other aspects of sport science, such as nutrition, sleep, physiological monitoring, and performance analysis. Because of the high prevalence of mental fatigue among physically active populations, including athletes, and the well-established deleterious effects of mental fatigue on sport and exercise performance, our study findings show the benefits for coaches to measure mental fatigue in their clients, and, importantly, to implement BET as method to help their clients deal with mental fatigue and optimize their resistance exercise training to enhance resilience and prolong fatiguability. Brain endurance training represents a viable long-term countermeasure against the deleterious effects of mental fatigue on strength endurance exercise performance. Athletes could readily incorporate BET into their standard gym training sessions by substituting brief rests between sets or exercises for brief demanding cognitive tasks. This combination of cognitive plus physical loading is designed to make the same exercise load feel harder or make an easier exercise load feel as hard. The former may be helpful for athletes wishing to maximize subsequent performance, whereas the latter may be suitable for athletes who are unable to perform at their highest level because of concerns about injury or overreaching. Brain endurance training is flexible and the detailed training plan can be adapted to the training needs of athletes, with short bouts of demanding cognitive tasks incorporated before, during, or after physical exercises. The BET training plan can also be modified to suit the macrocycle, with relatively more or less loading included at different times of the yearly cycle.

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