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

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1 **ABSTRACT**

2 Mental fatigue can impair resistance exercise performance. Brain Endurance Training (BET) –the
3 addition of demanding cognitive tasks to standard exercise training – improves endurance exercise
4 performance more than standard training. Although BET has yet to be evaluated with resistance
5 exercise, it is expected to improve performance, particularly when the performer feels mentally
6 fatigued. The study employed a pre-test (week 0), mid-test (week 3), post-test (week 6), follow-up
7 (week 9) design, with participants randomized to BET ($n=46$) or control (exercise training) ($n=45$)
8 groups. In testing sessions, participants performed chest press and squat jump exercises to failure
9 before (feeling fresh) and after (feeling tired) a 30-min cognitively demanding Stroop task. Training
10 comprised 5 BET or control training sessions/week for 6 weeks. In each training session,
11 participants completed four sets of each exercise to failure, with each exercise set preceded by a
12 3-min cognitive task (BET) or rest (control). Exercise performance (number of repetitions to failure)
13 and mental fatigue markers were assessed. In pre-testing, exercise performance did not differ
14 between groups. In mid-testing and post-testing, BET performed more chest press and squat jump
15 repetitions when fatigued by the 30-min Stroop than control. The mental fatigue elicited by the
16 Stroop task gradually declined with training in BET compared to control. In conclusion, BET
17 enhanced resistance exercise performance compared to standard training when tested subsequent
18 to a mentally-fatiguing cognitive task. These benefits were maintained weeks after training ended.
19 BET is an effective method to mitigate the deleterious effects of mental fatigue on resistance
20 exercise performance.

21

22 **Key Words:**

23 mental fatigue durability; repetitions to failure; resistance exercise

1 INTRODUCTION

2 Mental fatigue, defined as a psychobiological state induced by prolonged and demanding
3 cognitive demands, can impair athletes' exercise (37) and psychomotor (20) performance.
4 Although the mechanisms underlying the mental fatigue-performance relationship have yet to be
5 established, the putative candidates include prefrontal cortical processes, effort, motivation, and
6 resource depletion (9, 21, 22, 27). Mental fatigue in athletes is associated with sport participation
7 (37), travel (35) and sleep deprivation (14), and smartphone use (15, 16). The manifestations of
8 mental fatigue include subjective (e.g., lack of energy) (30), behavioral (e.g., impaired response
9 speed and accuracy) (29), and physiological (e.g., changes in heart rate variability and
10 electroencephalographic activity) (17, 18) responses.

11

12 It is well established that mental fatigue impairs aerobic endurance exercise performance (37).
13 This performance impairment has been attributed to greater perceived effort during states of
14 elevated mental fatigue in the absence of cardiorespiratory and metabolic changes (24). In
15 contrast, mental fatigue does seem to not impair maximal anaerobic exercise performance, such
16 as maximum contractions and efforts (6). It has been suggested that this lack of impairment in the
17 case of maximal performance is because cognitive resources are not relevant for these types of
18 exercise (1). Finally, studies examining the effects of mental fatigue on resistance exercise
19 performance are limited in number and mixed in outcome (1, 6). Notably, several recent studies
20 report reductions in leg contraction duration (3) and number of bench press and half-back squat
21 repetitions to failure (2, 10, 23) when mentally fatigued by a 30-min cognitive Stroop task.
22 Importantly, these recent findings agree with the meta-analytic review of earlier studies that
23 revealed that mental fatigue impairs both upper and lower body resistance exercise performance
24 (1). Grounded on this evidence, the present study explored the effect of mental fatigue on
25 resistance exercise performance and its mitigation by a training-based countermeasure.

26

27 Given the abovementioned evidence showing that mental fatigue can impair sport and exercise
28 performance, researchers have come up with countermeasures to help athletes mitigate the

problem (28). In terms of short-term countermeasures, the 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 (32, 33). Based on Marcora's *psychobiological model* of endurance exercise, BET requires athletes to complete cognitively demanding tasks alongside their standard exercise training tasks in order to subsequently enhance exercise performance by making exercise feel easier (26). The effectiveness of BET to improve subsequent endurance exercise has been demonstrated in several published studies, including those that used handgrip tasks (8, 9).

The current 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, 6), 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 participants 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 participants 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 participants 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 participants would experience less mental fatigue following BET than control.

METHODS

Experimental Approach to the Problem

The study employed a pre-test/training/mid-test/training/post-test followed by standard training and retention test design (see **Figure 1**), with participants randomly allocated to BET ($n = 46$) or control ($n = 45$) groups. During the intervention, participants completed 5 training sessions per week for 6 weeks. In each training session, all participants 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. Participants 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 participants performed standard (i.e., control) training for three weeks (5 sessions per week) before being re-tested at the end of week 9 (i.e., follow-up). In each testing session, participants performed chest press and squat jump exercises to failure when fresh and when fatigued by a 30-min 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 males, 42 females) resistance trained athletes were recruited and gave informed consent to participate. Their mean [SD] age was 29.42 [10.06] 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 five 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 XXXX in accordance with the Declaration of Helsinki (study protocol 93/2020). Participants were naïve to our study purposes and hypotheses. None dropped out. Power calculations using GPower software (13) indicated that with

a sample size of 91, our study was powered at 80% to detect significant ($p < 0.05$) between-within interaction effects ($f = .13$, $\eta_p^2 = .02$) corresponding to a small effect size by analysis of variance (7).

Measures

Subjective, behavioral, and physiological markers of mental fatigue were obtained. Using the VAS-MF, 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” and “maximum level of mental fatigue possible”. This scale is sensitive to changes in mental fatigue among athletes (29). Players also completed a 3-min Brief Psychomotor Vigilance Task (PVT-B) to assess mental alertness and readiness to perform. They were presented a visual stimulus, with a 1-4 s 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 (12). 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 (11, 17, 18).

Tasks

The chest press is an upper body (pectoral, deltoid, and triceps muscles) exercise: the participant laid on their back and kept their upper arms perpendicular to their body and their forearms perpendicular to the floor. At the start, the participant slowly pushed the bar/weights upwards until their elbows were almost straight and they felt tension in their upper chest (see Supplementary Materials). The squat jump is a lower body (quadriceps, glutes, and hamstring muscles) exercise: the participant 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 **Supplementary Materials**). 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 one of four colors (blue, green, red, yellow) was displayed on a 69 × 55 cm monitor in a different color on a black background, and participants 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 (i.e., 100% incongruent trials). The interstimulus interval was 1900 ms. A researcher sat behind the participant to ensure compliance.

Procedure

Testing. Participants completed four 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., $220 - \text{age}$) for 6-min, they performed the following sequence: determine chest press 6RM, 3-min rest, chest press repetitions to failure at 40% 6RM, 3-min rest, squat jump repetitions to failure, 30-min Stroop task, chest press repetitions to failure at 40% 6RM, 3-min rest, squat jump repetitions to failure. Testing took place at the same time of day. Before sessions, participants were encouraged to sleep at least 7 h the previous night, refrain from caffeine and alcohol for 12 h, refrain from vigorous physical activity for 24 h, and avoid creatine.

Training. Participants completed five training sessions per week for six 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-min by cycling at 60% of maximum predicted heart rate. Next, they performed four sets of chest press exercise at 40% 6RM to failure and four sets of squat jump exercise to failure. During the 3-min recovery after the warm-up cycling exercise and between the exercise sets, the BET group performed an incongruent Stroop task (i.e., $9 \times 3\text{-min} = 27\text{ min}$ of cognitive tasks) whereas the control group rested. At the end of each session, they warmed-down for 15-min by cycling at 85% of maximum predicted heart rate.

Our rationale for choosing to train these two exercises was twofold. First, bench press and squat jump are two of the most commonly studied upper 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 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.

Statistical Analysis

A series of mixed factorial ANOVAs, with group (BET, control) as the between-participant factor, and with time (0, 3, 6, 9 weeks) and test (before Stroop, after Stroop) as the within-participant 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-participant 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-participant 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 .02, .13, and .26 indicating small, medium, and large effect sizes, respectively (7). Significance was set at $p < .05$. Analyses were conducted using the Statistical Package for the Social Sciences (SPSS 29) software (IBM, USA).

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**). Participants 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-min Stroop task than they performed before the 30-min 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 to 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). RMSSD, 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.

1 *Training*

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

11

12 **DISCUSSION**

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

27

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 participants completed 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, 6).

Our second study purpose was to determine the effects of BET on resistance exercise performance. In support of our hypothesis, we found that BET participants completed more resistance exercise repetitions to failure when fatigued (i.e., after Stroop task) than control participants at every testing session apart from the baseline (week 0) pre-testing session. In other words, compared to 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 and lower body resistance exercise was always and similarly impaired in a fatigue state compared to 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 participants 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 post-training) declined slightly while remaining above pre-training levels.

The present 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 two previous BET studies showing that BET increased the cumulative amount of force produced during a 5-min bout of rhythmic handgrip exercise, when performed subsequent to and concurrent with a demanding cognitive exercise (i.e., in a fatigued state), compared to standard physical training (8, 9). It should be noted that these two studies also found that BET improved cumulative force production when in a fresh state, which is different to the findings of the present study. Other BET studies have found that cycling (4, 33) and running (32) endurance exercise are improved by BET compared to control (standard training). The paper with the two cycling studies (33) shows that the second, but not the first, of two 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 participants 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 to before the tasks (**Figure 3**). These findings are compatible with a large body of evidence showing that completing demanding exercise and/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 participants than controls, but we also found contrary evidence that the VAS ratings were similarly elevated in both groups. These data suggest that BET helped participants 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.

The present 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. Our findings therefore 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

1 resistance exercise in relation to weight training experience. Second, we only examined two
2 exercises, chest press and squat jump. It is likely that the effects of mental fatigue, and therefore
3 BET, will vary among different types of exercise. Such variations could be explored in
4 programmatic research plans. Third, we did not collect biomechanical and physiological measures,
5 such as movement kinematics, muscle activation patterns, and cortical oscillations, to gain an
6 understanding of potential mechanisms that mediate BET-related improvements in exercise
7 performance. Therefore, mechanistic studies could replicate and extend the present findings and
8 include a variety of measures to help identify the peripheral and/or central mechanism(s)
9 underpinning the improved resistance exercise performance observed here.

10
11 The current study provides the first evidence that BET improves resistance exercise
12 performance, with recreational athletes able to complete more repetitions to failure when in a
13 fatigued state. It also demonstrates that this benefit persists for several weeks after the end of the
14 additional cognitive training. These novel pieces of evidence add to those from past research
15 showing that BET improves endurance performance in various endurance exercise tasks, including
16 rhythmic handgrip as well as cycling and running. We have shown here how the cognitively
17 demanding elements of a BET training protocol can be easily completed between exercises (or
18 sets) by replacing rests with short-lasting cognitive tasks. Such an intermixed BET protocol is time
19 efficient and therefore more attractive to busy athletes. The cognitive tasks and scheduling regimes
20 can be optimized in future studies. Such investigations can also help to identify the underlying
21 psychobiological mechanism(s) that are responsible for BET-related improvements in resistance
22 exercise performance.

23 24 **PRACTICAL APPLICATIONS**

25 Our study findings should help strength and conditioning coaches to improve their
26 understanding of the mental side of resistance training and thereby help their clients practice and
27 perform better. These coaches have already increased their understanding of other aspects of
28 sport science, such as nutrition, sleep, physiological monitoring, and performance analysis. Due to

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.

BET 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 and/or exercises for brief demanding cognitive tasks. This combination of cognitive plus physical loading is designed to make the same exercise load feel harder and/or make an easier exercise load feel as hard. The former may be helpful for athletes wishing to maximise 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. BET 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, and/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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FIGURE LEGENDS

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.

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).

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.

Figure 1.

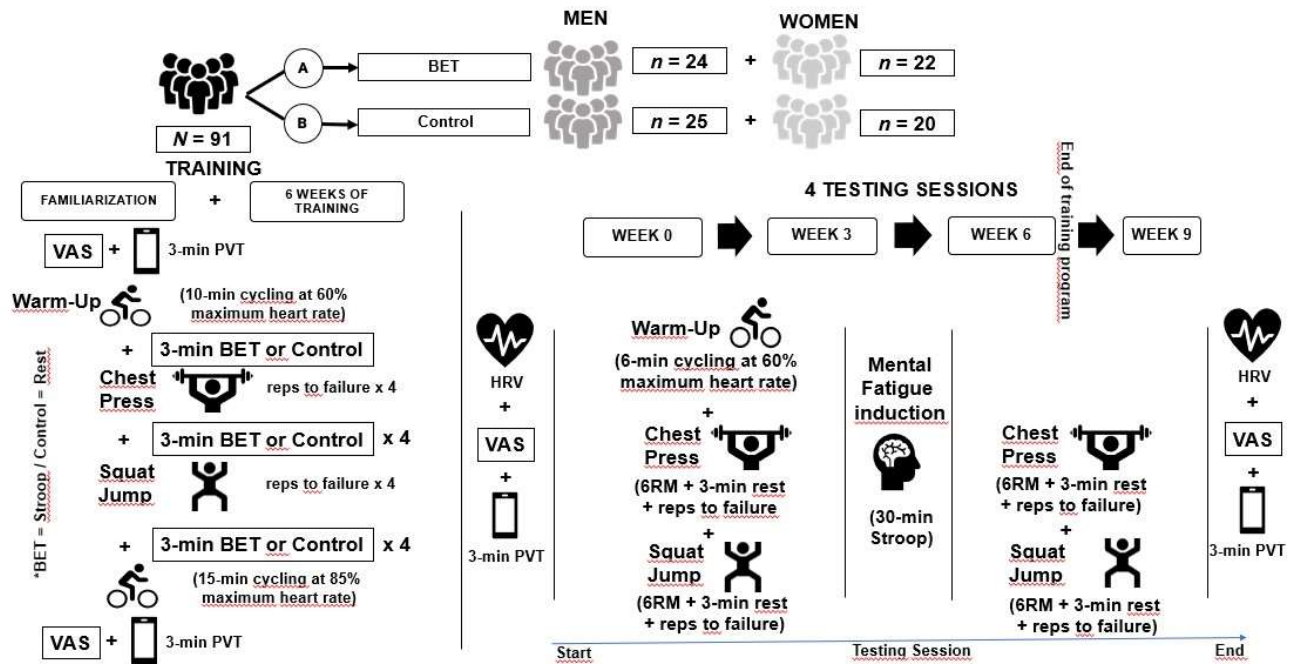


Figure 2.

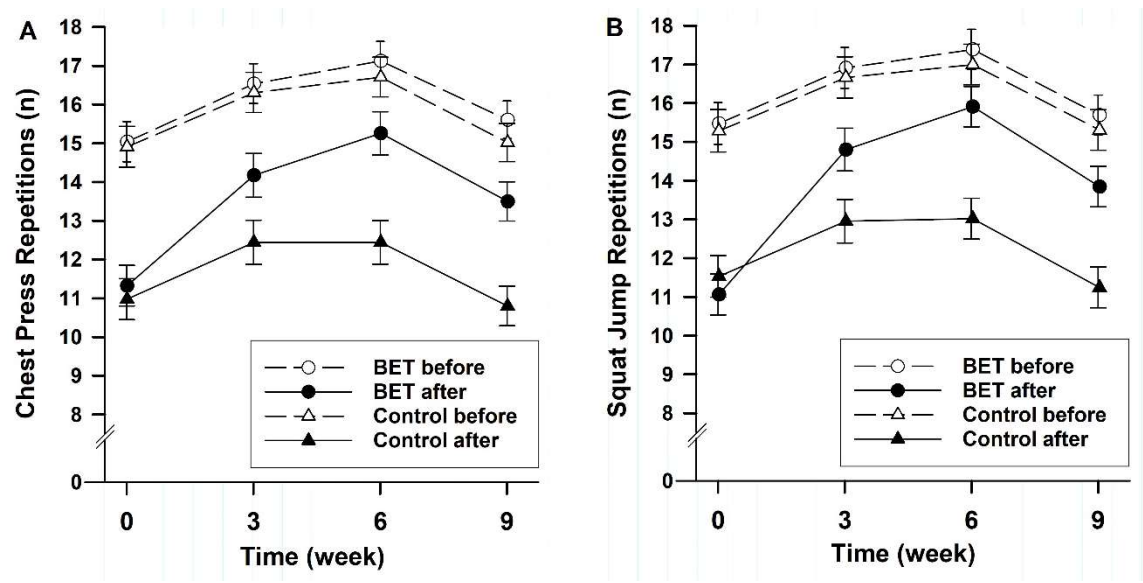


Figure 3.

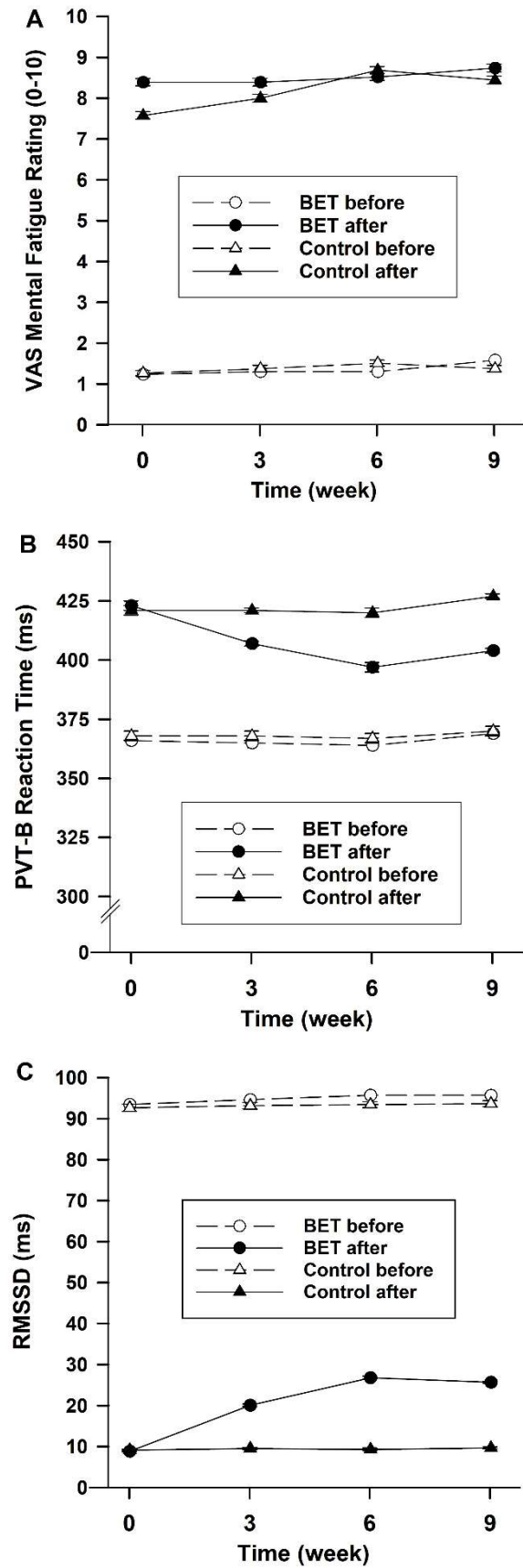


Figure 4.

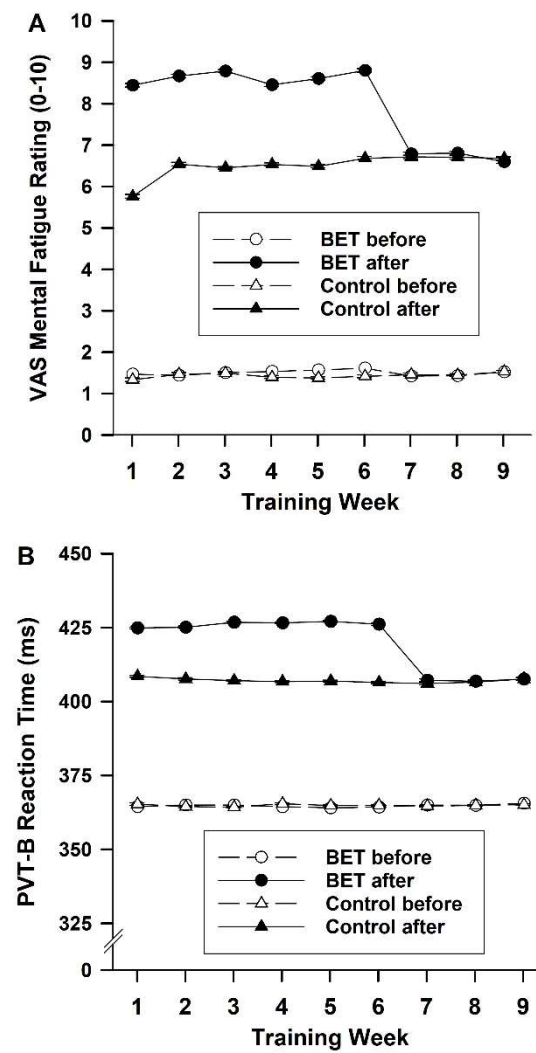


Table 1

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 weight lifting performance and mental fatigue indices.

	Group		Time		Test		Group x Time		Group x Test		Time x Test		Group x Time x 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	.03	241.03***	.89	694.01***	.89	20.04***	.41	38.71***	.30	11.18***	.28	19.64***	.40
Squat Jump Repetitions (n)	1.91	.02	407.28***	.93	1040.55***	.92	44.04***	.34	51.90***	.37	63.06***	.69	80.69***	.74
VAS-MF Ratings (0-10)	10.94***	.11	22.41***	.44	21175.80***	.99	9.13***	.24	13.93***	.14	7.97***	.22	6.37***	.18
PVT-B Reaction Time (ms)	25.32***	.22	64.23***	.69	1360.51***	.94	66.18***	.70	22.70***	.20	34.62***	.54	45.44***	.61
RMSSD (ms)	143.90***	.62	253.78***	.90	18624.19***	.99	196.73***	.87	64.13***	.42	193.64***	.87	225.94***	.89

Note: *** $p < .001$.

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 x Week		Group x Training		Week x Training		Group x Week x 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)	2305.52***	.96	139.21***	.93	210850.01***	.99	215.75***	.96	3192.32***	.97	154.77***	.94	191.15***	.95
PVT-B Reaction Time (ms)	1346.49***	.94	147.30***	.94	127859.20***	.99	133.46***	.93	2231.63***	.96	192.78***	.95	174.59***	.95

Note: *** $p < .001$.

LIST OF SUPPLEMENTAL DIGITAL CONTENT

Supplemental Digital Content 1. Exercises