

Wearing Ergonomically Designed Core Stability Shorts Improves Cognitive Control and Affect Following Acute Aerobic Exercise

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Abstract

This study examined whether wearing a pair of core-supporting gym shorts influenced cognitive control and mood state following aerobic exercise in young adults. Cognitive performance and the event-related P3 potential were measured. Twenty-four adults were assigned to either the core-supporting shorts group or the normal shorts group. Participants completed 30 minutes of an acute treadmill exercise involving walking and/or running at an intensity of 70% HR_{max}. They next performed a modified Sternberg memory task, in which participants encoded a letter array and determine if a probe letter had been presented in the preceding set of memory items. Results indicated that the core-supporting shorts group exhibited greater response accuracy and larger P3 amplitudes as compared to the normal shorts group. In addition, the core-supporting shorts group reported more pleasantness and relaxation than the normal shorts group. These results suggest that wearing the core-supporting shorts improves the cognitive control associated with working memory and induces a positive affect as well.

Keywords: Acute aerobic exercise; Working memory; Cognitive control; Event-related potentials; P3; Positive mood; Core stability

Introduction

There is a growing interest concerning the role of postural control in improving performance and overall health in sport activities, work, and daily life. Postural control is one of the limiting factors of performance, and the improvement of postural control by using techniques such as balance training appears to be an effective way to achieve better muscular activation during human locomotion [1]. Recent work in the area of athletic training has emphasized the importance of core stability. Core stability is defined as the ability to control the position and motion of the trunk. Such control of the area immediately over the pelvis allows optimum production, transfer and control of force and motion to the terminal segment of the spine in integrated athletic activities [2]. Thus, core stability performs an important role in maximizing force generation and minimizing joint loads in all types of athletic activities, and can be achieved through training of the muscles of the trunk and pelvis [2]. In addition, core stability reduces the probability of back injury, and enhances overall body balance [3].

The current interest in postural control, efficient training, and improved performance has led some sport manufacturers to provide equipment and sportswear that helps athletes maintain an ideal posture during training. Some of the more recent developments in sportswear are especially noteworthy. The importance of postural control during sport activities is well documented as mentioned above. Also well appreciated is the improvement of cognitive function following aerobic exercise [4]. In the present study, we tested the hypothesis that sportswear specifically designed to enhance core stability would facilitate cognitive function following aerobic exercise that was performed while wearing such sportswear.

Recent studies in cognitive neuroscience have indicated the beneficial effects of acute aerobic exercise on cognitive control using not only behavioral indices (e.g., Response Time (RT), and response accuracy) but also event-related potentials (ERPs). Cognitive control refers to “the ability to orchestrate thought and action in accord with internal goals” [5]. Inhibition, cognitive flexibility, and working memory are thought to comprise the core processes that underlie such

abilities [6]. For example, Hillman et al. [4] investigated the effects of acute aerobic exercise on cognitive control using a modified flanker task, and found that reduced interference in the task condition required greater amounts of cognitive control as indexed by changes in the scalp-recorded P3 component of an ERP. Several ERP studies have replicated the findings of Hillman et al. These studies indicate the selective nature of the effects on task conditions which necessitate the upregulation of cognitive control [4,7-9]. However, other ERP studies indicate general, rather than selective, effects of acute aerobic exercise irrespective of task conditions [10,11]. Thus, empirical evidence regarding the effects of acute aerobic exercise on cognitive control remains inconclusive. Most of these previous studies have focused on the inhibitory aspects of cognitive control rather than on working memory aspects (see Pontifex et al. [12] for one exception). The current study was designed to elucidate the effects of acute aerobic exercise on working memory, which involves a different aspect of cognitive control.

We used a modified Sternberg task to assess working memory function [13]. This task required participants to encode a horizontal array of uppercase letters (3, 5, or 7 letters), and then determine whether or not a subsequently presented single lowercase probe letter appeared in the encoded array. In this situation, more cognitive control is demanded for larger set sizes. Pontifex et al. examined the effects of acute aerobic and resistance exercise on working memory using the Sternberg task [12]. They found shorter RT after aerobic exercise, but not after resistance exercise, suggesting that exercise mode affects whether or not acute exercise has an effect on the cognitive control involved with working memory. In addition, Pontifex et al. showed that decreases in RT following aerobic exercise were larger for set sizes

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5 and 7 relative to set size 3 [12]. Thus, it is likely that the beneficial effects of acute aerobic exercise are disproportionately larger for tasks requiring greater amounts of working memory. However, because they did not investigate neural correlates of task performance by recording ERPs, alterations in memory search processing following acute exercise remain unclear.

One novel aspect of the present study was to extend the findings of Pontifex et al. by recording the P3 component of the ERP (hereinafter referred to as P3) during the Sternberg task. The particular utility of P3 amplitude as an index of attentional processing capacity has been emphasized [12,14]. P3 has been used in conjunction with the Sternberg task to investigate working memory capacity and it was found that the P3 becomes smaller as the memory set-size increases [15,16]. In this study, we recorded the P3 elicited by a single lowercase probe letter to assess the capacity of working memory that has been shown to change with memory set-size. While previous studies have consistently demonstrated increases in P3 amplitude after acute aerobic exercise [4,7-11,17], to our knowledge no study has investigated changes in P3 amplitude that are associated with working memory demands after a single bout of aerobic exercise.

We can infer the neuronal mechanisms that underlie improvement of cognitive control after exercise from previous studies on animals. Acute aerobic exercise enhances neurochemicals that improve plasticity and neuronal survival such as Brain-Derived Neurotrophic Factor (BDNF) and insulin-like growth factors [18,19]. These neurochemicals have also been reported to increase following aerobic exercise in humans [20-22]. One mode of function of the above and other neurochemicals could be to induce a positive affect. Ashby et al. suggest that a positive mood might improve cognitive performance due to increased dopamine release in the anterior cingulate and prefrontal cortex [23]. In addition, BDNF modulates not only memory processing but also emotion emanating from regulation in the hippocampus [24]. Decreased BDNF in the hippocampus is associated with depression, while antidepressants elevate BDNF levels [25].

The second novel aspect of the current study emphasized the role of postural control during exercise. Previous studies have suggested that maintaining the correct posture during physical activity and using muscles properly diminishes the stress on muscles and thus lowers fatigue [26-30]. This suggests the possibility that core stability is associated with more efficient exercising. Thus, sportswear that aids in proper muscle use might well have an influence on sports performance. We felt it probable that core stability would act to diminish fatigue, and we further suspected that the increased postural control provided by ergogenic aids would result in increased positive affect and, as a consequence, better cognitive performance. Acute aerobic exercise has been associated not only with better cognitive function, but also with elevated mood, positive affect modulation, and stress reduction [4,7,9,10-12,31-35].

Given that positive affect induced by acute exercise improves cognitive performance, we hypothesized that cognitive function would be facilitated by wearing comfortable sportswear that was designed to provide core stability during running. To test this hypothesis, we asked half of the participants to wear a pair of core-supporting gym shorts that was designed to keep the abdomen and lower back properly aligned during running. The core-supporting shorts included a rigid panel and bilateral closure straps to support the core muscles. This design was created to achieve an upright and proper running posture (Figure 1).

A preliminary goal of this study was to replicate and extend the beneficial effects of acute exercise on working memory function by recording the P3 component during a Sternberg memory task. The main purpose of the study was to clarify whether wearing a pair of core-supporting shorts would result in enhanced activation of the brain and thus produce an improved task performance on the Sternberg memory task. As mentioned above, the stabilization of running posture is thought to aid in the achievement of an effective and efficient aerobic fitness. It is reasonable to presume that stabilization of the running posture augments positive affect and thus results in a better performance.

Based on previous findings, we predicted larger P3s and a better performance following a single bout of exercise. We also predicted that this effect would be larger for higher memory workload conditions (i.e., a larger memory set size). Given the overall importance of running posture, as memory set size increased individuals who wore a pair of core-supporting shorts would be expected to demonstrate larger P3s and better task performance than individuals who wore a pair of normal shorts. Taken together, it was predicted that group differences in both P3 amplitudes and task performance would be more prominent as a function of memory set size (i.e., set size 7 and possibly 5). This effect would be revealed as an interaction between group and memory set size.

Method

Participants

Twenty-six right-handed undergraduate students were recruited from the general Waseda University student population. Data of two participants were later excluded due to below 50% response accuracy and other technical problems. Thus analyses were conducted on twenty-four participants, 11 of which were females). The overall age (mean \pm SD) was 21.4 ± 1.3 years. The detailed characteristics of the participants for both groups are presented in Table 1. No participant had a history of neurological or cardiovascular disease. All had normal or corrected-to-normal vision and were paid 1,000 yen/hour (about 10 U.S. dollars) for completion of the experiment. Written informed consent was obtained. This study was approved by the Waseda University Ethics Committee.

The modified Sternberg memory task

Participants performed a modified Sternberg memory task, which required them to encode a letter array memory set (3, 5, or 7 letters)

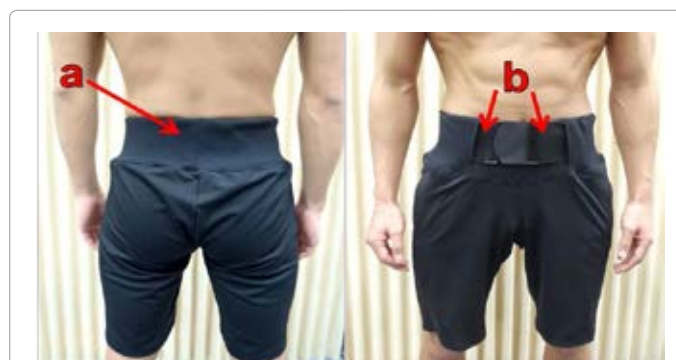


Figure 1: The core-supporting shorts used in the present study. The belt contains a rigid panel (a), which the participant fastened tightly around his waist with bilateral closure straps (b) at the frontal surface to support the core muscles.

	Normal shorts (n = 11)		Core-supporting shorts (n = 13)	
	Males (n = 6)	Females (n = 5)	Males (n = 7)	Females (n = 6)
Age (years)	21.5 ± 1.0	20.4 ± 1.1	21.9 ± 1.7	21.7 ± 0.8
BMI (kg/m ²)	23.3 ± 1.5	20.7 ± 1.8	22.8 ± 1.8	21.7 ± 2.6
VO _{2max} (ml/kg/min)	54.7 ± 8.2	40.3 ± 7.2	52.7 ± 3.1	40.9 ± 3.1
HR _{max} (bpm)	191.7 ± 8.3	190.0 ± 7.0	192.4 ± 6.8	183.0 ± 8.7
Mean Exercise HR (bpm)	138.3 ± 12.6	134.7 ± 2.7	136.1 ± 8.1	127.1 ± 13.4
Mean Exercise RPE	11.8 ± 1.0	12.3 ± 0.3	11.9 ± 0.7	12.7 ± 1.1
Resting HR (bpm)	63.4 ± 4.0	69.0 ± 7.7	65.1 ± 6.7	65.7 ± 4.1
Post Exercise HR (bpm)	64.5 ± 3.9	69.0 ± 3.7	66.9 ± 4.3	69.7 ± 12.4

Table 1: All data are presented as means ± SD. BMI, body mass index; VO_{2max}, maximal oxygen consumption; HR_{max}, maximal heart rate; Mean Exercise HR, average HR during the exercise session; RPE, rating of perceived exertion; Mean Exercise RPE, average RPE during the exercise session; Resting HR, HR prior to cognitive task during the rest session; Post Exercise HR prior to the cognitive task during exercise session.

and decide whether or not a single probe letter was present in the preceding array. Participants were required to perform a right index finger press when the probe letter was in the memory set and a left index finger press when the probe letter was not. They were asked to respond as quickly and accurately as possible. They performed 208 trials (4 blocks × 52 trials). All stimuli were white letters presented on the black background of a CRT monitor at a distance of 100 cm. The letter array to be encoded was presented for 2500 ms. Following the encoded array, the screen was blank for 3000 ms and then the probe letter was presented for 200 ms, with a 1500 ms response window. The visual angle subtended by a letter was 0.6° × 0.9° (horizontal and vertical angle, respectively).

We also evaluated a flanker task and a task-switching task. Because these tasks measure aspects of cognitive control that are different from working memory, we will report those results elsewhere.

Procedure

Participants visited the laboratory on three separate days. On Day 1, they completed the Physical Activity Readiness Questionnaire [36], and the Edinburgh Handedness Inventory [37]. To evaluate maximal oxygen consumption (VO_{2max}) and maximal heart rate (HR_{max}), the graded exercise test (GXT) was performed on a treadmill. On Day 2 and Day 3, the participants were assigned to either the exercise session or the rest session. The interval between these sessions was at least 4 days, and the order of the sessions was counterbalanced across participants. During the exercise session, participants completed 30 minutes of walking and/or jogging on a motor-driven treadmill with the exercise intensity varied in order to maintain the HR at 70% of HR_{max}. This adjustment procedure is routinely used to control exercise intensity in studies that investigate the effects of acute aerobic exercise on cognitive function [7-10,17,38,39]. We recorded HR every minute and ratings of perceived exertion (RPE) every five minutes [40]. During the rest session, participants were seated on a chair and were instructed to read a newspaper for 30 minutes. We assessed transient mood states before and after each session using the Mood Check List-Short Form 2 [41]. Following the completion of each session, the participants were prepared for the Electroencephalogram (EEG) recordings and performed the Sternberg memory task, during which time task performance and EEG were recorded.

To test the effect of sportswear on cognition, we randomly assigned participants to either the core-supporting shorts group or the normal shorts group. Thus, half of the participants wore a pair of core-supporting shorts (Core-Move, Ozaki Inc.) and the other half wore a pair of normal shorts during the exercise session. The participants neither received information about the characteristics of their shorts nor about those of the other participants. Each participant was simply

instructed to “Change your clothes and put on a sweat suit that we prepared for you since your clothes could be soaked with sweat”. During the rest session all participants came to the laboratory in, and remained in, casual clothing.

Cardiorespiratory fitness assessment

The GXT was performed using a treadmill ramp protocol, in which the speed and grade of the treadmill were increased by a fixed metabolic equivalent (MET) every minute. A computerized indirect calorimetry system collected breath-by-breath values for oxygen consumption and carbon dioxide production and from these values, the respiratory exchange ratio (RER) was calculated. The HR was recorded throughout the test and RPE was assessed every minute. The GXT was stopped when the participants achieved at least two of the three following criteria: (1) a peak heart rate at or above 95% of age-predicted HR_{max}, (2) RPE ≥ 18, (3) RER ≥ 1.10.

Self-Ratings of mood states

The MCL-S2 scale is composed of 12 items, which are divided into three sub-scales: “4 items for pleasantness”, “4 items for relaxation”, and “4 items for anxiety”. Participants were asked about their feeling at the moment and each item was rated on a 7-point Likert scale from 1 “very much so” to 7 “not at all”. The items relating to the three sub-scales were averaged separately. MCL-S2’s reliability has been previously established (Cronbach’s α coefficient=0.84).

EEG recording

The EEG was recorded from 128 sites with Ag/AgCl electrodes. For the detection of artifacts, the vertical and horizontal electrooculogram (EOG) was recorded from above and below the left eye and left and right outer canthi, respectively. The electrical potentials were recorded with a bandwidth of DC to 205 Hz, using a Biosemi Active Two system (Biosemi Inc.). All physiological signals were digitized at a rate of 1024 Hz.

Data analysis

Processing of the EEG was performed with a software package (Brain Vision Analyzer, Brain Products). The EEG was re-referenced to the average reference and corrected for ocular movement artifacts using the procedure described by Gratton et al. [42]. The EEG data were segmented from 500 ms pre-probe to 1500 ms post-probe for averaging. Trials in which the RT fell outside of a 100 to 1500 ms window or the EEG amplitude exceeded a threshold of 100 μ V during the segmented epoch were excluded from ERP averaging. Across sessions and groups, means of 37, 37, and 34 trials were averaged for set-sizes of 3, 5, and 7, respectively, across session and groups. The numbers of averaged trials did not differ between groups for all set sizes ($p > .05$). The ERPs were

bandpass-filtered with a 0.1 Hz to 30 Hz (roll-off 12 dB). The P3 elicited by the probe letter was measured as the average amplitude within a time window of 400 to 600 ms over CPz and Pz, where P3 showed maximum amplitude, relative to a baseline defined as the mean voltage from -200 to 0 ms pre-probe.

Statistical analysis

P3 amplitudes were analyzed using a 2 by 3 by 2 ANOVA on session (exercise and rest), memory set-size (3, 5, and 7), and electrode site (CPz and Pz). For RT and response accuracy, a 2 by 3 ANOVA was performed on session and memory set. We reported the Greenhouse-Geisser epsilon value along with the original degrees of freedom and if the assumption of sphericity was violated, we adjusted the significance level. The alpha level was set at $p=.05$. Where post hoc comparisons were required, the Bonferroni correction was applied.

We tested the effect of wearing a pair of core-supporting shorts on working memory function. However, we did not ask participants to conform in wear between the rest and the exercise sessions. Therefore, we analyzed only the exercise session to investigate the effect of wearing the core-supporting shorts. After we investigated the effect of acute exercise on working memory function, we tested the effect of wearing the core-supporting shorts on both P3 amplitude and task performance. P3 amplitude was analyzed using a 3 by 2 by 2 ANOVA on memory set, electrode site and group (core-support and normal shorts). Both RT and response accuracy were analyzed using a 3 by 2 ANOVA on memory set and group.

For the MCL-S2 scale ratings, each sub-scale score (i.e., pleasantness, relaxation, and anxiety) was analyzed using a 2 by 2 ANOVA on the timing of assessments (pre- and post-exercise) and group (core-supporting shorts and normal shorts).

Results

Clarification of the acute-exercise effect

Task performance: The mean RTs were 703 ms for set-size 3, 799 ms for set-size 5, and 828 ms for set-size 7, respectively. A two-way ANOVA revealed a main effect of set-size ($F(2, 22)=87.93, p<.001, p\eta^2=.79$). RT became longer with increasing set-size (set-size 3 vs. 5, $p<.001$; set-size 3 vs. 7, $p<.001$; set-size 5 vs. 7, $p=.02$). RT did not differ between the rest and the exercise sessions ($F(1, 23)=0.13, p=.72$). Neither a main effect of session ($F(1, 23)=0.13, p=.72$) nor an interaction between session and set-size ($F(2, 22)=0.48, p=.61$) was obtained.

Mean response accuracies were 93.4% for set-size 3, 90.3% for set-size 5, and 77.9% for set-size 7, respectively. A two-way ANOVA revealed a main effect of set-size ($F(2, 22)=133.18, p<.001, p\eta^2=.85$). Performance became less accurate with increasing set-size (set-size 3 vs. 5, $p=.004$; set-size 3 vs. 7, $p<.001$; set-size 5 vs. 7, $p<.001$). Neither a main effect of session ($F(1, 23)=0.43$) nor an interaction was obtained ($F(2, 22)=1.01$).

Response of P3 to the probe letter: Figure 2 shows the grand-averaged ERP waveforms for each memory set-size for both exercise and rest sessions. The P3s were larger in the exercise session than in the rest session. A three-way ANOVA supported this observation with a main effect of session ($F(1, 23)=5.34, p=.03$) (Table 2). A main effect of set-size was also significant ($F(2, 22)=18.10, p<.001, p\eta^2=.44$). Post-hoc tests showed that P3 decreased with increasing set-size (set-size 3 vs. 5, $p=.002$; set-size 3 vs. 7, $p<.001$). In addition, an interaction of session by electrode was obtained ($F(1, 23)=5.13, p=.03$). Post-hoc tests showed that increased P3s in the exercise condition relative to the rest session were observed only at Pz ($p=.02$), but not at CPz.

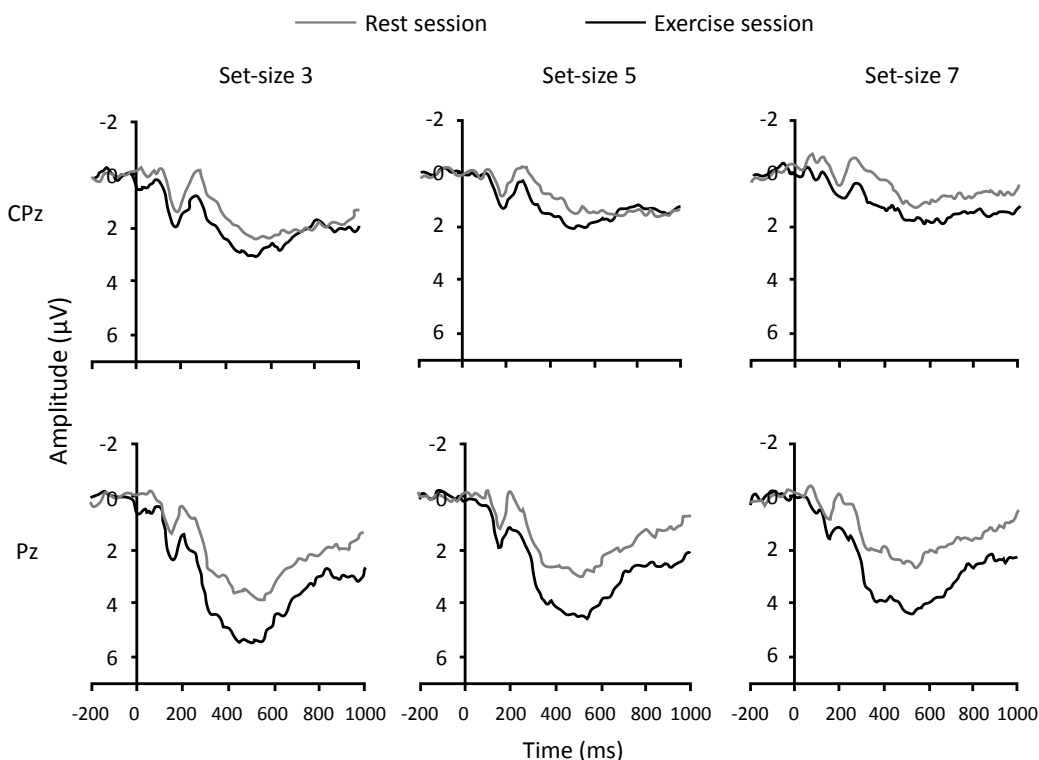


Figure 2: Grand averaged ERP waveforms for each memory set size in both rest and exercise sessions at the CPz (upper panel) and Pz (lower panel) electrode sites.

	Rest Session		Exercise Session	
	CPz	Pz	CPz	Pz
Set-size 3	2.1 ± 0.4	3.5 ± 0.7	2.8 ± 0.6	5.1 ± 0.6
Set-size 5	1.2 ± 0.3	2.7 ± 0.5	1.8 ± 0.5	4.2 ± 0.4
Set-size 7	1.0 ± 0.5	2.3 ± 0.7	1.6 ± 0.5	4.1 ± 0.6

Table 2: Mean ± SEM P3 amplitude (µV) for each memory set size in rest and exercise session at CPz and Pz electrode site.

Effect of wearing a pair of core-supporting shorts

Task performance: Mean RTs of the core-supporting shorts group were 714 ms for set-size 3, 824 ms for set-size 5, and 842 ms for set-size 7, while mean RTs of the normal shorts group were 698 ms for set-size 3, 782 ms for set-size 5, and 813 ms for set-size 7, respectively. A two-way ANOVA revealed a main effect of memory set ($F(2, 21)=55.21, p<.001, \eta^2=.71$), mirroring our first analysis mentioned above. Post-hoc tests revealed that RT became longer with increasing set-size (set-size 3 vs. 5, $p<.001$). RT did not differ between groups ($F(1, 22)=0.56, p=.46$).

Mean response accuracies were 93.4% for set-size 3, 92.5% for set-size 5, and 80.5% for set-size 7 in the core-supporting shorts group, whereas they were 92.1% for set-size 3, 88.1% for set-size 5, and 73.3% for set-size 7 in the normal shorts group, respectively. A two-way ANOVA revealed a main effect of set-size ($F(2, 21)=125.68, p<.001, \eta^2=.85$). Post-hoc tests revealed that performance became less accurate with increasing set-size (all comparisons, $p\leq.05$). A main effect of group was also significant ($F(1, 22)=4.89, p=.04$). Furthermore, an interaction of group by set-size was revealed ($F(2, 21)=3.74, p=.04$). This interaction disappeared after the arcsine transformation was applied to response accuracies ($F(2, 21)=1.73, p=.19$), although other effects remained

significant. Because of our *a priori* hypothesis that the core-supporting sportswear would have beneficial effects on cognitive control, we also conducted planned comparisons to examine the group difference within each set size using *t*-tests. These planned comparisons revealed that the core-supporting shorts group performed more accurately than the normal shorts group for the larger set sizes 5 ($p=.05$) and 7 ($p=.03$), but not for set size 3 ($p=.46$).

Responses of P3 to the probe letter: Figure 3 shows the grand-averaged ERP waveforms for each group during the exercise session. A 3-way ANOVA was applied to mean P3 amplitudes for each memory set (Table 3). It revealed a main effect of memory set ($F(2, 21)=10.10, p<.001, \eta^2=.31$), showing smaller P3s for the larger set-sizes 5 ($p=.02$) and 7 ($p<.001$) as compared to set-size 3. It also revealed larger P3s for the core-supporting shorts group than for the normal shorts group ($F(1, 22)=4.40, p=.05$), and larger P3s at Pz as compared to those at CPz ($F(1, 22)=31.27, p<.001$). Importantly, an interaction of group by set-size was also marginally significant ($F(2, 21)=3.04, p=.06$). As we expected, P3 amplitudes for the three different set-sizes showed a similar relationship with respect to response accuracy. Thus, we compared group differences for each memory set, applying the Bonferroni correction that yielded an alpha of .017. These ad-hoc comparisons revealed a significantly larger P3 amplitude only for set size 5 ($p=.013$), but not for set sizes 3 ($p=.04$) and 7 ($p=.20$).

Mood states: Figure 4 shows the MCL-S2 scale ratings before and after exercise. Each sub-scale score was analyzed using a two-way ANOVA. The core-supporting shorts group showed higher pleasantness ($F(1, 22)=6.79, p=.02$) and relaxation ($F(1, 22)=7.57, p=.012$) than the normal shorts group. In addition, the pleasantness score became higher after exercise than before exercise ($F(1, 22)=12.49,$

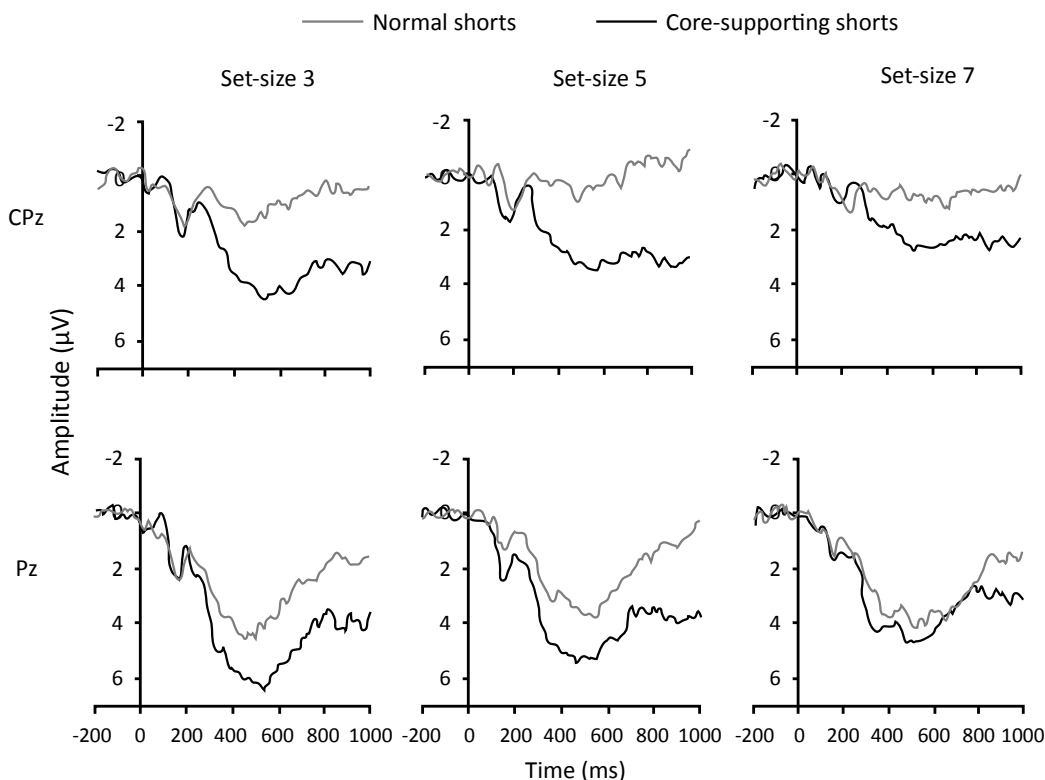


Figure 3: Grand averaged ERP waveforms for each group during the exercise session for each set-size at CPz (upper panel) and Pz (lower panel).

	Normal Shorts		Core-Supporting Shorts	
	CPz	Pz	CPz	Pz
Set-size 3	1.3 ± 0.7	4.0 ± 1.0	4.1 ± 0.8	6.0 ± 0.7
Set-size 5	0.4 ± 0.8	3.3 ± 0.6	3.1 ± 0.6	5.0 ± 0.6
Set-size 7	0.6 ± 0.7	3.7 ± 1.0	2.4 ± 0.5	4.4 ± 0.8

Table 3: Mean ± SEM P3 amplitude (µV) for each group during the exercise session in each set size at CPz and Pz electrode site.

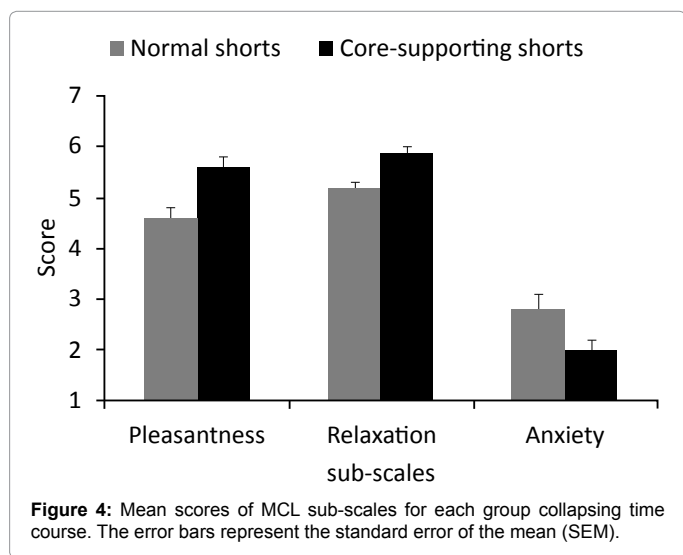


Figure 4: Mean scores of MCL sub-scales for each group collapsing time course. The error bars represent the standard error of the mean (SEM).

$p=.002$). Also, the anxiety score became lower after exercise than before exercise ($F(1, 22)=11.29, p=.003$). However, no interaction between timing of assessments and group was observed in any sub-scale.

Discussion

A preliminary goal of our study was to replicate and extend previous findings concerning the effects of acute aerobic exercise on cognitive control, using a modified Sternberg memory task. We focused on working memory function because the effects of acute exercise on memory processes are poorly understood [43]. Although neither response time nor response accuracy was improved following a single bout of exercise, increased P3 amplitudes were observed in the exercise session as compared to the rest session. The second, and main aim of our study was to test whether core stability, as augmented by wearing uniquely-designed shorts, would facilitate cognitive control and induce a positive affect. The core-supporting shorts group did indeed show a more accurate performance, with larger P3 amplitudes and a more positive affect as compared to the normal shorts group. Although the arcsine transformation applied to response accuracy eliminated the interaction of group by set-size, planned comparisons based on our hypothesis still revealed significant differences between groups both for set-sizes 5 and 7, supporting the supposition that the core-supporting shorts had beneficial effects.

The present results replicated previous findings that P3 became consistently larger following acute aerobic exercise [4,7-11,17]. The P3 amplitude is believed to increase in proportion to the degree of brain attentional resources being committed during stimulus engagement [14]. Thus, it is reasonable to conclude that the participants allocated more attentional resources to the memory search process and target identification after aerobic exercise. Apart from the above attentional-allocation interpretation, the increased P3 amplitude observed in the exercise session might be physiologically explained by a transient

augmentation of bioactive chemicals as well as increases in regional cerebral blood flow following a single bout of exercise. These physiological effects have been documented in previous studies [12,44]. The present study additionally demonstrated that beneficial effects of acute aerobic exercise can be observed in the Sternberg memory task requiring variable amounts of working memory demands.

We found a prolonged RT and a decreased response accuracy with increasing memory set-size. According to Sternberg [45], participants retrieve stored memory items and sequentially compare them with the probe letter one by one, resulting in a linear increase in RT with increasing memory set-size. Thus, increasing RTs as a function of set-size likely represents the duration of the memory search process.

The P3 amplitudes were reduced as a function of memory set-size in both groups. It is plausible that the reduced P3 amplitude with increasing set-size was due to a lowered processing capacity. In the Sternberg memory task particularly, a reduced P3 amplitude with increasing set-size may be explained by the participants' equivocation about their confidence of performance accuracy [46-48]. This equivocation would grow as set-size increased, because more discriminating processes would be required. In addition, it is also possible that the reduction of P3 amplitude with increasing memory load might be due to a preferential allocation of resources to memory rehearsal, thus depleting the attentional resources available for the probe letter comparison processes [15].

Another possible explanation for the linear reduction of P3 with increasing set-size might be due to a latency jitter of P3 [49]. For larger set-sizes, participants would be expected to take longer for the comparison of stored memory items with the probe letter, and terminate searching with different timing among trials, depending on the location of the probe letter in preceding memory items. Because of the latency jitter associated with a larger variability of termination of memory search, P3 amplitude likely decreases with increasing set-size.

Our main goal was to determine if proper posture during exercise contributes to the improvement of cognitive control. Therefore, we asked half of the participants to wear a pair of core-supporting shorts that helped them keep a proper posture during the treadmill running. We found that performance was more accurate for the core-supporting shorts group than for the normal shorts group. There was no speed-accuracy tradeoff in the exercise session. Importantly, group differences were most prominent for the more demanding tasks (i.e., set-size 5 and 7), as we hypothesized. These results suggest that proper posture during exercise might assist memory-search processing or minimize impairment of memory retrieval under conditions of a higher memory load.

The most striking finding was that in the exercise session the P3 amplitudes were significantly larger for the core-supporting shorts group than for the normal shorts group. We predicted that the group difference in P3 amplitudes during exercise session would be clearest for set-size 5 and 7 (i.e., more demanding task conditions). In fact, we found significant group differences only for set-size 5, but not for set-sizes 3 and 7. This result, on the surface, seems to contradict the response accuracy explanation and our prediction as well. Based on a comparison between set sizes 3 and 5, the group effect was pronounced for set-size 5 in accordance with the hypothesis that the P3 effect emerges in the more demanding task. However, in contradiction to our hypothesis, P3 amplitude did not differ between groups for set-size 7. One possible explanation for this lack of group difference is reduced P3 amplitude for set-size 7 in the core-supporting shorts group. Although a group by

set-size interaction was marginally significant ($p=.06$), decomposition of the two-way interaction which examined the set-size effect within each group revealed a set-size main effect for the core-supporting group ($p=.07$), but not for the normal shorts group ($p=.26$). That is, only the core-supporting group exhibited a smaller P3 amplitude for larger set-sizes. This may have been due to the participants' equivocation, a preferential allocation of resources to memory rehearsal, and latency jitter as discussed above. By contrast, for the normal shorts group, the P3 amplitude was small even for set-size 3. Thus no additional set-size effects could be observed. Accordingly, it is speculated that the reduced P3 amplitude for set-size 7 in the core-supporting shorts group blurred the group differences. These suggestions are speculative and further research using additional set-sizes (i.e., set-sizes 4 and 6) is needed to clarify this issue. Importantly, the larger P3 amplitudes observed in the core-supporting shorts group suggest that running/walking with the proper posture might help participants facilitate cognitive control and/or increase their confidence relative to response accuracy.

Finally, it should be noted that the core-supporting shorts group derived more positive affect than the normal shorts group regardless of the timing of assessments. This suggests that wearing the core-supporting shorts per se provided participants with a more positive feeling. Prior studies have shown that physical activity is positively correlated with the enhancement of mental health [50]. Aerobic exercise particularly decreases both anxiety [51] and depression [52] during and after activity. Psychophysiological research has confirmed the beneficial effects of exercise as assessed via frontal EEG (alpha band) asymmetry which was utilized as a biological marker of emotional state [51-54]. Trained runners exhibit a larger positive affective response during and after continuous 10-minute bouts of treadmill exercise as compared with untrained runners [55]. We can infer that the trained runners had achieved a greater core stability through long-term training. Similarly, the enhanced pleasantness and relaxation during and after exercise seen in the core-supporting shorts group may have been due to increased core stability. On the other hand, it is also possible that wearing the nicely-designed sportswear for the supporting muscles of the trunk and pelvis resulted in an increased positive affect even before the dose of exercise, as suggested by the higher scores on pleasantness and relaxation in the core-supporting shorts group.

As is the case with beneficial effects on cognitive control, the mechanisms that underlie the affective changes associated with acute exercise are still unclear, although previous studies have suggested the involvement of hyperthermia, which is increased in proportion to the intensity of exercise (i.e., the thermogenic hypothesis, see Petruzzello et al. [51]), catecholamines [56], and endorphins [57]. Concerning the catecholamines, an increased dopamine release has been documented following acute treadmill running in rats [58]. Although future research should clarify the underlying mechanisms in humans, it is possible that the increased positive affect seen during and after acute treadmill running in our study might be mediated by a transient increase in dopamine release.

It should be noted that the present study included methodological limitations. First, although we provided no information regarding the characteristics of the core-supporting shorts to the participants, they likely found the core-supporting shorts special in terms of their unique and comfortable design. The participants' awareness of the special nature of the core-supporting shorts likely influenced the results. Second, in retrospect our between-participants experimental design might not have been the best way to examine the effects of wearing core-supporting shorts on cognitive control. In the rest session, the

participants wore casual clothes that differed from both the core-supporting shorts and the normal shorts. Because this procedure could have produced unexpected cognitive biases, a full within-participants counterbalanced design would have been more appropriate. On the other hand, it would have been difficult to concoct a reason for the participants to wear the core-supporting shorts during the rest session, and we did not want the participants to be aware of our research aim. Thus, we did not employ a full within-participants design. Further research is needed to overcome these limitations, using similar looking but non-core-supporting sportswear as a control in both the rest and exercise conditions.

In sum, the present study reconfirmed the robust beneficial effects of acute exercise on cognitive control. In addition, it was suggested that core stability enhanced by core-supporting shorts may facilitate these positive acute-exercise effects. It was also suggested that simply wearing the core-supporting shorts induced a positive affect even without exercise, which might be another factor affecting performance.

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