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Brief Report

Neuroelectric indices of goal maintenance following a single bout of physical activity

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ABSTRACT

Previous event-related brain potential (ERP) investigations have demonstrated that single bouts of physical activity have transient benefits to aspects of cognitive control. However, this line of research has yet to explore goal maintenance. ERPs were collected using a within-participants design with young-adults following 30-min of both moderate walking and a non-exercise control session. Participants completed three conditions of an AX-continuous performance task (AX-CPT) that targeted goal maintenance processes, which were placed under greater cognitive demand when contexts were conflicting, as indexed by modulation of the N2 and P3 components. Following exercise, individuals exhibited increased accuracy for target trials, and P3 amplitude was greater at midline-parietal sites for both target trials and non-target trials. These results suggest that a single bout of aerobic exercise may facilitate goal maintenance processes and enable individuals to better inhibit extraneous neural activity to allocate greater attentional resources towards the updating and revision of goal representations.

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In recent years, a growing number of reports have demonstrated the beneficial effects of single bouts of physical activity on transient changes in cognitive control across the lifespan (Hillman et al., 2003, 2009; Kamijo et al., 2009; Lambourne and Tomporowski, 2010), with much of the evidence stemming from functional neuroimaging techniques such as event-related brain potentials (ERPs). Increases in the amplitude of the P3 component (i.e., P300 or P3b), which is elicited when individuals attend to or discriminate between stimuli (Polich and Kok, 1995), have been observed following exercise and suggest a greater propensity to inhibit neuronal activity unrelated to the task at hand, and facilitate attentional processing (Polich, 2007). Such evidence provides support for the development of programs designed to promote health-related fitness (Sallis et al., 1997; Stewart et al., 2004) and combat the growing number of individuals engaging in sedentary and unfit lifestyles (Flegal et al., 2010; Pate et al., 2006). Goal maintenance, which is necessary for the updating of internal contextual representations that influence planning and direct behavior (Braver and Barch, 2002), remains one aspect of cognitive control that has not been examined in the acute exercise literature.

Previous studies investigating goal maintenance have largely focused on participant's performance during the AX-continuous performance task (AX-CPT; Paxton et al., 2008), which has also been widely incorporated into research on attentional vigilance (Riccio and Reynolds, 2001). The AX-CPT involves correctly responding to target trials that occur when the letter "X" (correct-probe) is immediately preceded by the letter "A" (correct-cue). Non-target trials occur when probes are letters other than X (referred to collectively as "Y") and/or cues are letters other than A (referred to collectively as "B"). Thus, participants encounter four types of trials: AX, AY, BX, and BY (Braver and Barch, 2002). Additional research has demonstrated that ERP components such as the P3, can be modulated by, and are sensitive to, changes in stimulus context across multiple versions of the AX-CPT (Dias et al., 2003). Accordingly, ERP data were collected during a 3-condition AX-CPT following a single 30 min aerobic exercise bout, relative to a non-exercise control session. AX-CPT conditions consisted of varying trial probabilities to manipulate local and global stimulus contexts. It was hypothesized that following exercise participants would exhibit larger P3 amplitude and shorter P3 latency for probes of AX and AY trials. Further, this increase was expected to be selectively larger when global and local contexts were conflicting and greater cognitive demand is placed on goal maintenance processes.

During the first visit, thirty-seven undergraduate students (18 females, age = 19.7 ± 1.3 years; see Table 1) provided demographic information and completed a small neuropsychological battery before undergoing a modified Balke protocol (American College of Sports Medicine, 2010) to determine maximal oxygen

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Table 1
Mean (SD) values for participant demographics and exercise data.

Measure	All participants	Males	Females
Age (years)	19.7 (1.3)	20.2 (1.5)	19.1 (.9)
K-BIT (IQ)	105.5 (7.4)	105.1 (7.7)	105.8 (7.2)
BMI (kg/m^2)	23.1 (2.6)	23.8 (2.9)	22.3 (2.0)
$VO2_{max}$ (ml/kg/min)	47.2 (7.3)	51.2 (5.4)	43.1 (6.8)
Baseline HR (bpm)	72.1 (9.6)	72.5 (9.5)	71.6 (9.7)
HR_{max} (bpm)	193.0 (8.5)	194.7 (8.3)	191.1 (8.5)
Postrest HR (bpm)	70.4 (12.4)	70.2 (11.4)	70.7 (13.8)
Postexercise HR (bpm)	72.5 (10.9)	73.4 (10.3)	72.1 (11.7)

Note: HR_{max} is the maximum heart rate achieved during the cardiorespiratory fitness test; Postrest HR is the heart rate prior to cognitive testing on the rest day; Postexercise HR is the heart rate prior to cognitive testing after a single bout of aerobic exercise.

consumption. During the second and third visits, participants were counterbalanced into two different experimental groups such that half of the participants received the non-exercise control session prior to the aerobic exercise session, and vice versa. During the non-exercise control session participants sat and quietly read the university daily newspaper for 30 min while heart rate (HR) was recorded every 2 min and ratings of perceived exertion (RPE; Borg, 1970) were collected every 6 min. During the exercise session participants completed 30 min of aerobic exercise on a motor driven treadmill at an intensity of 60% of maximal HR ($M = 117.2 \pm 5.7$ bpm), which has been suggested to offer the greatest cognitive benefits (Kamijo et al., 2004), while HR and RPE were recorded every 2 min. Time was also recorded from the cessation of each experimental session to when participants began their first AX-CPT practice block (exercise: $M = 20.2 \pm 6.4$ min; non-exercise control: $M = 23.5 \pm 8.1$ min; $t(36) = 1.5$, $p = .15$). During this time, HR returned to within 10% of baseline levels following exercise.

Electroencephalographic (EEG) activity was recorded in an extended montage based on the International 10-10 system (Chatrian et al., 1985) as participants completed three conditions of the AX-CPT, which manipulated the frequency of the cue–probe pairings, such that one trial type was presented the majority of the time (64%) while the other three trial types were less probable (12% each). This resulted in AX-64, AY-64, and BX-64 conditions, with the name corresponding to the trial that was presented 64% of the time. Participants were instructed to make a corresponding button press using a response pad as quickly and accurately as possible for AX trials. Participants received two blocks of each condition (six total blocks), with each block consisting of 175 randomized trials which were comprised of 5 cm tall white letters presented at a 2° visual angle for 100 ms on a black background. Block order was randomized and counterbalanced across all participants, with 1 min of rest provided between each block. Recordings were referenced to averaged mastoids (M1, M2), with AFz as the ground electrode, and impedances <10 kΩ. Continuous data were digitized at a sampling rate of 500 Hz, amplified 500× with a DC to 70 Hz filter, and a 60 Hz notch filter was applied using a Neuroscan Synamps amplifier (Neuro, Inc., Charlotte, NC). Offline data reduction included electrooculographic correction using a spatial filter (Compumedics Neuroscan, 2003), and all trials with a response error or artifact exceeding ±75 μV were rejected. The P3 component was quantified as the maximum positive deflection occurring within a 300–600 ms latency window. Repeated measure MANOVAs were conducted for behavioral and ERP data, with all factors treated as dependent variables. Analyses with three or more within-subjects levels used the Greenhouse–Geisser statistic and significance levels were set at $p = .05$. Post hoc comparisons were conducted using Bonferroni correction.

The 3-condition AX-CPT successfully altered the cognitive demand placed on goal maintenance processes as indexed by longer RTs for AX trials when global and local stimulus

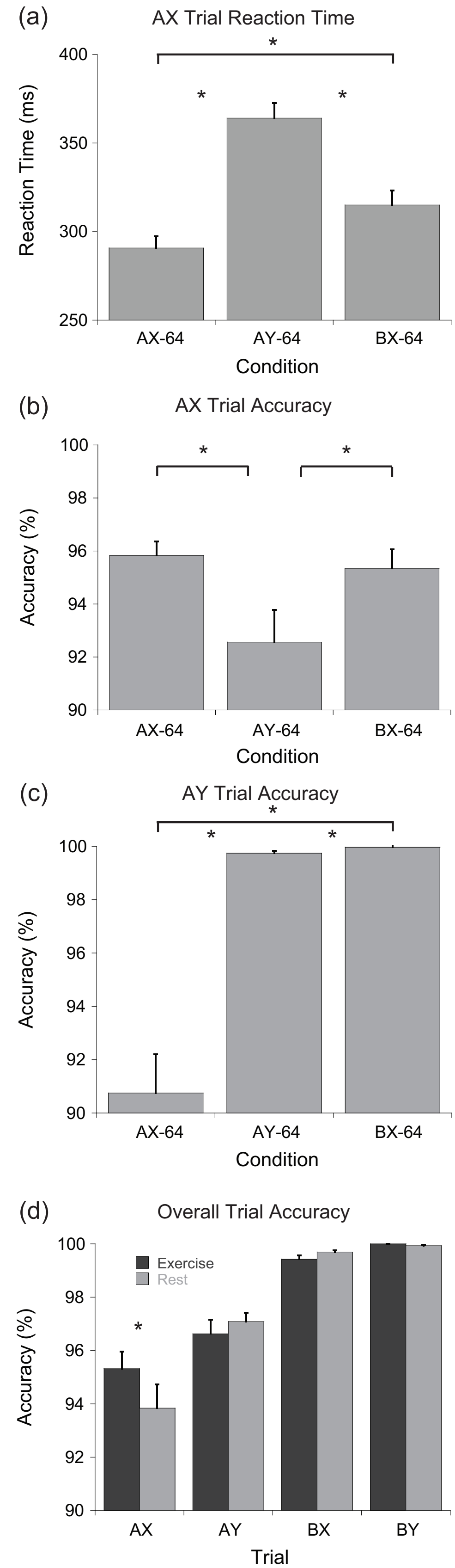

Fig. 1. Behavioral data indicating: (a) modulations in AX trial RT across the 3 task conditions, (b) decreased AX trial accuracy in the AY condition, (c) decreased AY trial accuracy in the AX condition, and (d) a combined increase in AX trial accuracy across all conditions following exercise.

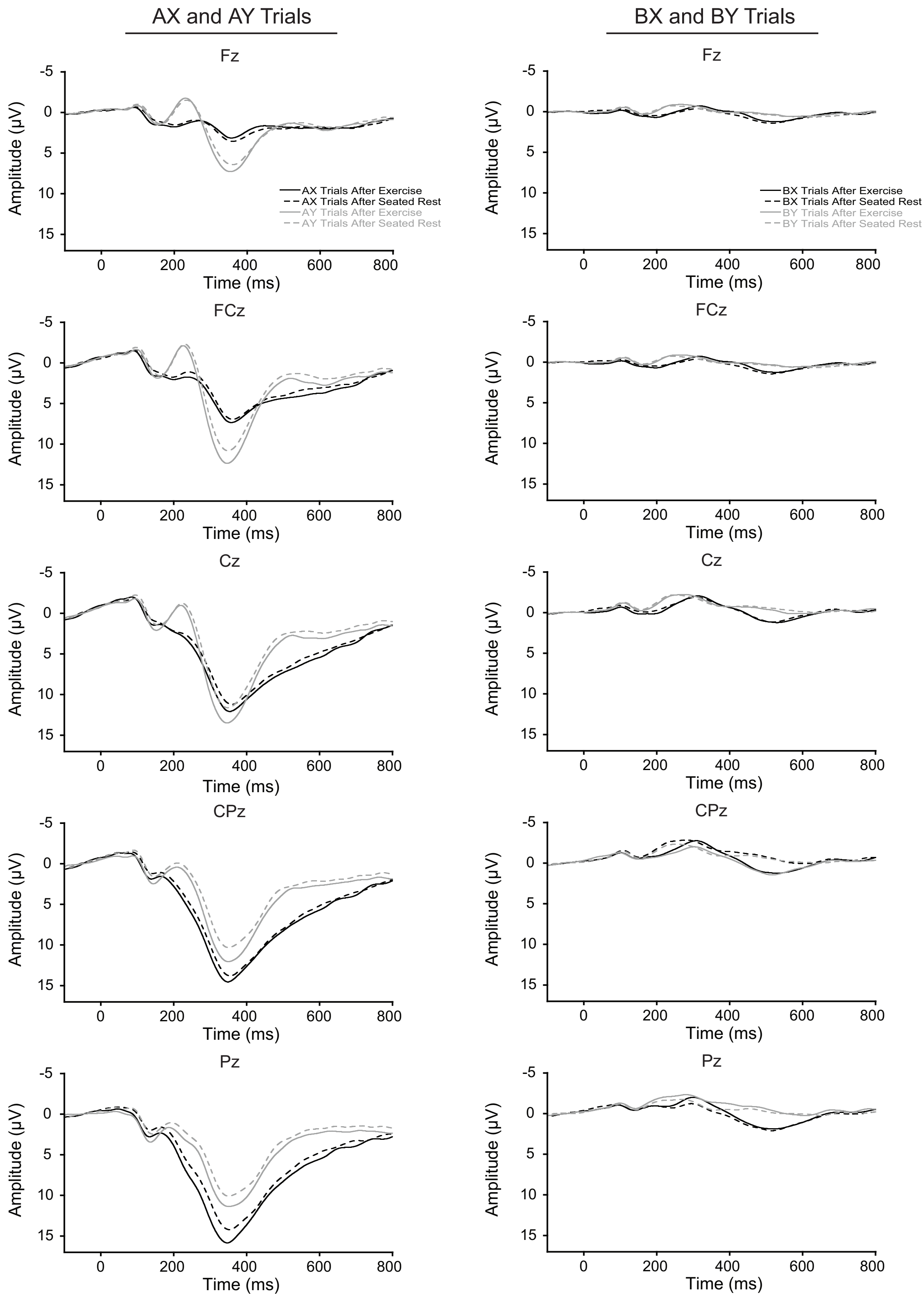

Fig. 2. Grand average waveforms of combined AX-CPT conditions at midline sites extending from Fz to Pz. P3 components to the probe of AX and AY trials can be seen on the left, while BX and BY trials are shown on the right.

contexts were conflicting, $t(36) \geq 5.8$, $p \leq .001$, $d \geq .54$; an effect that was most prominent in the AY-64 condition (due to the build-up of a prepotent response to the probe; see Fig. 1a). Accuracy data provided additional support for this notion with participants demonstrating decreased AX accuracy in the AY-64 condition (see Fig. 1b), $t(36) \geq 2.9$, $p \leq .01$, $d \geq .46$, and producing significantly more AY errors in the AX-64 condition (see Fig. 1c), $t(36) \geq 3.3$, $p \leq .01$, $d \geq .69$. The current findings are also consonant with previous ERP investigations of cognitive control following moderate aerobic exercise. Although P3 latency remained stable, increases in P3 amplitude were observed across all conditions for probes of AY trials at Cz and CPz sites, $t(36) \geq 2.9$, $p \leq .01$, $d \geq .33$, and for AY and AX trials at the Pz site (see Fig. 2), $t(36) \geq 2.6$, $p \leq .015$, $d \geq .30$, when compared to the non-exercise control session. Contrary to the a priori hypothesis this effect occurred similarly across all task conditions, thus the exercise findings appear general rather than selective. Participants also exhibited a small, yet significant increase in target trial accuracy (see Fig. 1d), $t(36) = 2.3$, $p < .025$, $d = .32$. Observed increases in P3 amplitude suggest a greater allocation of attentional resources when trials engender the updating and maintenance of stimulus context to sustain accurate goal representations in support of task performance (Braver et al., 2005; Donchin and Coles, 1988).

The findings from the current study coincide with current meta-analytic reviews, which suggest that physical activity has a small, but positive effect on cognition (Etnier et al., 1997; Tomporowski, 2003). Although the current design of the AX-CPT was conducive for investigating goal maintenance processes, it did not allow for large changes in performance (made evident from the high accuracy scores). As such, one might expect that acute exercise-related effects may increase when participants encounter more difficult task situations (Hillman et al., 2003). A further limitation of the current study was the absence of a baseline condition to serve as a control for the non-exercise resting condition. However, care was taken in controlling for exercise-induced arousal and choosing an appropriate resting condition that kept participants engaged and awake. The pattern of results suggests that a single bout of moderate aerobic exercise may be beneficial before engaging in tasks that rely on goal maintenance. Similar evidence involving other cognitive processes and scholastic performance (Best, 2010; Hillman et al., 2011; Lambourne and Tomporowski, 2010) is continuing to mount despite the seemingly unclear impact on public health. Future research should continue to pursue the different aspects of cognition that are impacted by acute exercise, and determine how these effects persist over multiple exercise bouts or vary with levels of physical fitness. Developing a broad understanding of these relationships could have considerable implications for organizations and programs that strive for superior cognitive aptitude, and promote the adequate health of individuals.

Conflict of interest

No conflicting financial interests exist.

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