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The effects of single bouts of aerobic exercise, exergaming, and videogame play on cognitive control

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HIGHLIGHTS

- The effects of exergames on neurocognition were examined.
- Treadmill-based exercise, in contrast to exergaming, facilitated neurocognition.
- Exergames may not incur the same benefits to brain and cognition as traditional physical activities.

ABSTRACT

Objective: The effects of single bouts of aerobic exercise, exergaming, and action videogame play on event-related brain potentials (ERPs) and task performance indices of cognitive control were investigated using a modified flanker task that manipulated demands of attentional inhibition.
Methods: Participants completed four counterbalanced sessions of 20 min of activity intervention (i.e., seated rest, seated videogame play, and treadmill-based and exergame-based aerobic exercise at 60% HR_{max}) followed by cognitive testing once heart rate (HR) returned to within 10% of pre-activity levels.
Results: Results indicated decreased RT interference following treadmill exercise relative to seated rest and videogame play. P3 amplitude was increased following treadmill exercise relative to rest, suggesting an increased allocation of attentional resources during stimulus engagement. The seated videogame and exergame conditions did not differ from any other condition.
Conclusions: The findings indicate that single bouts of treadmill exercise may improve cognitive control through an increase in the allocation of attentional resources and greater interference control during cognitively demanding tasks. However, similar benefits may not be derived following short bouts of aerobic exergaming or seated videogame participation.
Significance: Although exergames may increase physical activity participation, they may not exert the same benefits to brain and cognition as more traditional physical activity behaviors.

1. Introduction

Today's industrial and technological societies are becoming increasingly sedentary and unfit, leading to an increased incidence of a number of chronic diseases across the human lifespan (American College of Sports Medicine, 2010). In addition to the physical concerns manifested through a lack of physical activity, concerns for brain health and cognition also exist. That is, a growing body of research has demonstrated a link between physical activity and the health of brain structure and function (Colcombe et al., 2004; Hall et al., 2001), with research indicating that aerobic fitness has a disproportionately greater influence on aspects of cognition requiring greater amounts of cognitive control (Colcombe and Kramer, 2003; Hillman et al., 2008).

Cognitive control describes a subset of operations responsible for adjustments in perceptual selection, response biasing, and the online maintenance of contextual information (Botvinick et al., 2001). These processes describe goal-directed behaviors concerned with the selection, scheduling, and coordination of complex processes underlying perception, memory, and action (Diamond, 2006). The core processes of cognitive control have been categorized along the domains of inhibition (i.e., the ability to ignore distracters and maintain focus), working memory (i.e., the ability to hold information in one's mind and manipulate it), and cognitive flexibility (i.e., the ability to switch perspectives, attention, or response mappings; Diamond, 2006).

Investigations into alterations in cognitive control following a single session of aerobic exercise have primarily used tasks that tap inhibitory control, which relates to the ability to gate task irrel-

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evant information from the environment and inhibit a prepotent response in order to make a correct response. Findings from these investigations have indicated that the transient effects of exercise on cognition may result in improvements in inhibitory control following the cessation of the exercise bout (Hogervorst et al., 1996; Lichtman and Poser, 1983; Tomporowski et al., 2005). Specifically, Hogervorst et al. (1996) and Lichtman and Poser (1983) observed facilitations in cognitive performance during the condition of a Stroop task requiring the greatest amount of inhibitory control immediately following a 20–40 min bout of aerobic exercise. Similarly, Tomporowski et al. (2005) observed performance enhancements on the Paced Auditory Serial Addition Test following a 30 min bout of exercise. Taken together, these results suggest transient benefits to inhibitory aspects of cognitive control following a single bout of exercise.

Beyond behavioral indices of task performance, the examination of neuroelectric activity provides an index of specific cognitive operations, which occur between stimulus encoding and response production that are influenced by some factor. To date, the vast majority of acute exercise research that has incorporated neuroelectric assessment has investigated the P3 (or P300) component of an event-related brain potential (ERP). The P3 is a prominent positive-going component of the stimulus-locked ERP occurring approximately 300–800 ms following the presentation of a stimulus. The amplitude of this component has been related to the amount of attentional resources allocated toward the stimulus environment, while the latency is thought to be a metric of stimulus classification (i.e., stimulus processing) speed (Polich, 2007).

Relative to the exercise literature, increases in P3 amplitude and decreases in P3 latency have been observed following single bouts of aerobic exercise (Hillman et al., 2003; Kamijo et al., 2007, 2009). Specifically, after a single, 30 min bout of exercise, an increase in P3 amplitude was observed across conditions of a flanker, while a reduction in P3 latency was observed only during trials requiring greater amounts of inhibitory control (Hillman et al., 2003). Further, Kamijo et al. (2007) indicated that following three different exercise intensities (e.g., light, moderate, and hard), RT was reduced across conditions of a flanker task, which required variable amounts of inhibitory control. However, after light and moderate exercise intensities, increases in P3 amplitude and decreases in P3 latency were observed selectively for condition requiring greater amounts of inhibitory control. Collectively, these findings suggest that participation in a single bout of aerobic exercise has general benefits to cognition, with selectively greater benefits for task components requiring greater amounts of inhibitory control, as reflected by neuroelectric indices of attentional resource allocation (i.e., P3 amplitude) and cognitive processing speed (i.e., P3 latency).

Despite these improvements in cognition following exercise, a growing portion of industrialized societies are shifting their physical activity behaviors from more traditional "gym based" activities (i.e., running, cycling, etc.) towards computer based "exergames". These exergames (e.g., Dance Dance Revolution® [DDR®], Nintendo Wii™, and Wii Fit™) provide an individual with the ability to physically interact with a virtual environment, with their specific movements being captured or tracked and then depicted on screen via a virtual character. Kinesiological investigations of these "exergames" has observed that participation may serve to increase individuals' energy expenditure during tasks offered by Wii Fit™, eliciting a MET[1] value of 3.4 ± .09 and falling within a moderately intense classification (Miyachi et al., 2010).

Since these exergames are relatively new, limited research is available to determine the efficacy of exergames on cognition. However, researchers have explored the effects of single sessions of videogame play on cognitive function. Orosy-Fildes and Allan (1989) indicated that a single bout of videogaming aided in reducing participants' RT by as much as 50 ms on a simple RT task. Additional results indicated that following a single session of both violent and non-violent videogame play, individuals' scored better on a task requiring selective attention, working memory, auditory discrimination, and mathematics (Bartlett et al., 2009), suggesting that a single bout of videogame play may facilitate a number of aspects of cognition, including cognitive control. Given the increased reliance on exergaming for physical activity, additional research is necessary to determine the relationship between videogame play, exercise, and exergaming as well as how participation in these activities influences cognition.

The purpose of the proposed study was to assess the effects of single bouts of videogame play, exergaming, and aerobic exercise on task performance and neuroelectric indices of inhibitory aspects of cognitive control. It was hypothesized that a single bout of moderate aerobic exercise would serve to enhance cognition as measured via task performance and the P3 component, replicating previous research (Hillman et al., 2003, 2009; Davranche et al., 2009; Kamijo et al., 2009; Pontifex et al., 2009). Following treadmill-based aerobic exercise, it was expected that participants would respond more accurately and exhibit shorter RT, suggesting transient improvements in task performance following the cessation of exercise. Additionally, participants were expected to exhibit larger P3 amplitude and shorter P3 latency, indicating greater allocation of attentional resources and faster cognitive processing speed, respectively. Exergaming was expected to exhibit a similar effect given that the exercise elicited by the games was similar in intensity and duration. Lastly, based on previous research, seated videogame play was predicted to show similar facilitations in cognition.

2. Method

2.1. Participants

Thirty-six college-aged young adults (18 females; age range: 18–25 years) were recruited from the undergraduate population at the University of Illinois at Urbana-Champaign. All participants provided written informed consent, which was approved by the Institutional Review Board of the University of Illinois at Urbana-Champaign. Participants completed the Physical Activity Readiness Questionnaire (PAR-Q), the Edinburgh handedness inventory (Thomas et al., 1992; Oldfield, 1971), and reported normal or corrected to normal vision. Participants were instructed to abstain from physical activity on the days they visited the laboratory. Demographic and fitness data for all participants are provided in Table 1.

Table 1
Mean (SD) values for participant demographic and fitness data.

Variable	All participants (*M* ± *SD*)	Females (*M* ± *SD*)	Males (*M* ± *SD*)
Sample size (*n*)	36	18	18
Age (years)	21.2 ± 1.5	20.6 ± 1.3	21.8 ± 1.6
BMI	23.3 ± 3.0	22.7 ± 2.6	24.3 ± 3.2
IQ (K-BIT composite)	106.8 ± 7.3	106.6 ± 7.7	107.1 ± 7.1
VO_{2max} (mL/kg/min)	45.2 ± 5.9	41.5 ± 4.2	48.9 ± 5.0
Max HR (bpm)	195.1 ± 7.9	193.8 ± 8.1	196.3 ± 7.8
Max RPE	17.9 ± 1.5	17.9 ± 1.4	17.9 ± 1.5

Note: BMI = Body Mass Index; K-BIT = Kaufman Brief Intelligence Test; PA = Physical Activity; RPE = Ratings of perceived exertion (Borg, 1970).

[1] MET, or metabolic equivalent of task, provides a practical means of expressing the energetic cost of physical activity participation as a function of resting metabolic rate with one MET corresponding to rest and increasing MET values representing multiples of the resting metabolic rate (Ainsworth et al., 1993).