

Original article

Failure to identify an acute exercise effect on executive function assessed by the Wisconsin Card Sorting Test

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Abstract

Purpose: Acute exercise has been linked to the facilitation of executive function, but little is known regarding executive function assessed by the Wisconsin Card Sorting Test (WCST). The present research consisted of two experiments aimed to determine whether acute aerobic exercise influences successive WCST performance.

Methods: In Study 1, 27 young adults were randomly assigned to the exercise or reading control group and then instructed to perform the WCST before and after assigned treatment. In exercise group, participants completed a single bout aerobic exercise with moderate intensity for 20 min on a stationary bike. A similar experimental protocol was replicated in Study 2 with 24 late middle-aged adults to look for age differences during adulthood and control for a potential ceiling effect at young adult age.

Results: Although a significant time effect was observed in young adults, both studies revealed that there was no main effect for treatment or an interaction between treatment and time on any of the WCST indices.

Conclusion: Acute aerobic exercise failed to influence executive function as assessed by the WCST, revealing that this classical neuropsychological test tapping executive function may not be sensitive to acute exercise. Our findings suggest that acute exercise does not broadly affect the entire family of executive functions, or its effect on a specific aspect of executive function may be task-dependent, as proposed by Etnier and Chang (2009).

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1. Introduction

The beneficial effect of physical activity on cognitive function has been well documented in the past few decades. Narrative reviews of empirical studies consistently conclude that acute exercise leads to improvements in cognitive function.^{1,2} This argument has been supported by more recent meta-analytic reviews, which show that acute exercise has

small but positive effects on cognitive function following an exercise session.^{3,4}

Considering the consistently positive effects of a single bout of exercise on cognitive performance, one line of research has emphasized the exploration of acute exercise effects on specific cognitive functions, such as basic information processing, memory, crystallized intelligence, attention, and executive function.^{3,4} Among these different aspects of cognition, executive function, which is a higher-order cognitive function, has recently received substantial attention.⁵ For example, a variety of studies have examined the effects of acute exercise on executive function as measured by

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behavioral assessments^{6–11} and by neuroelectric measurements.^{12–15} Notably, the findings derived from these studies have been mixed; some studies demonstrate facilitative effects of acute exercise^{6–8,11,16,17} and other studies fail to reveal a beneficial effect.^{9,18,19} These inconsistent findings may be attributed not only to differences in the populations tested and whether cognitive testing was performed during or after exercise (in-task vs. off-task), but also to the complexity of the construct of executive function.

Although executive function is generally recognized as a higher-order or prefrontal lobe-dependent domain of cognition,²⁰ executive function is not a simple construct, but is instead an umbrella term that involves a number of sub-cognitive processes. Some researchers define executive function as including working memory, reasoning, task flexibility, problem-solving, and planning.^{21,22} Other researchers have suggested that executive function involves the sub-cognitive processes of volition, planning, purposeful behavior, and effective performance,²³ or processes that address novelty, planning, and acting on the appropriate strategies for conducting performance.²⁴ Acute exercise plausibly has a specific influence on certain aspects of executive function. Etnier and Chang⁵ suggested that researchers who devote time to exploring the effects of exercise on executive function should be careful with regard to recognizing the complexity of executive function and ensuring the selection of the appropriate cognitive tasks to assess the particular aspect of executive function that they are interested in. Etnier and Chang⁵ identified 29 neuropsychological assessments that have been widely utilized to assess executive function. The Wisconsin Card Sorting Test (WCST) was the most commonly used task and, therefore, was selected as the outcome measure of the present study.

The WCST²⁵ has been used extensively to examine frontal cortex function, a brain region that is involved in executive functioning.^{26–29} The WCST has been considered the gold standard of executive function tests^{25,30} and is suggested to assess several aspects of executive function, such as selective attention, updating, switching, and inhibition. The task requires participants to sort cards by identifying the key characteristic of the card, maintain the task set until the characteristic for sorting is changed, and inhibit the tendency to use incorrect characteristics.^{22,31} Few studies have examined the effects of acute aerobic exercise on executive function using the WCST.^{16,32–34} Dietrich and Sparling³³ compared the performance differences between higher and basic cognitive processes while exercising (i.e., in-task research) at moderate intensity. The results showed that performance on the WCST and the Paced Auditory Serial Addition Task, both requiring executive function, was impaired, whereas no differences were observed for the Brief Kaufman Intelligence Test or the Peabody Picture Vocabulary, which are considered to test non-executive function tasks. More recently, Del Giorgio et al.³² demonstrated that WCST performance decreased during exercise at two exercise intensities (i.e., ventilatory threshold and 75% ventilatory threshold). Wang et al.³⁴ investigated whether exercise intensity moderates the relationship between exercise

and executive function as assessed using the WCST. They observed that when exercising, the WCST performance was impaired only in the high-intensity exercise group, while it was maintained in the low- and moderate-intensity groups. In sum, these studies demonstrated that WCST performance was typically impaired *during* exercise particularly at higher intensity levels.

In contrast, the alterations in WCST performance following the cessation of exercise (i.e., off-task research) remain elusive. For example in young adults, WCST performance was impaired immediately following exercise at ventilatory threshold, whereas performance was improved immediately following exercise at 75% ventilatory threshold.³² Nevertheless, improved WCST performance was observed following acute exercise at moderate intensity in children with attention deficit hyperactivity disorder (ADHD).¹⁶ Clearly, the two studies utilized different exercise protocols and populations, which limits our understanding of the associated influence of acute exercise on WCST performance following exercise and, therefore, merits further exploration.

Taken together, the effects of acute exercise on executive function have drawn rising attention, but the results have been ambiguous and this may be in part due to the lack of consistency in the measures of executive function used. Our understanding of the effects of acute exercise on executive function would benefit from the use of classical neuropsychological assessments with well-understood characteristics; in particular, we recommend expanding our understanding of the effects on the most frequently used measure of executive function, the WCST.⁵ Most previous studies that utilized the WCST focused on exploring the effects during exercise, or observed inconsistent cognitive effects following exercise. This indicates that the after-effects of acute exercise on WCST performance are still an issue in need for further research. Therefore, the purpose of the current investigation was to determine the effects of a single bout of aerobic exercise on executive function as assessed by the WCST performed after exercise cessation. Acute exercise was hypothesized to facilitate WCST performance.

2. Study 1

2.1. Methods

2.1.1. Overview

Young adults were randomly assigned to either perform 30 min of moderate intensity exercise or to a 30-min reading condition. Performance on the WCST was measured prior to and immediately after the assigned treatment condition.

2.1.2. Participants

Twenty-eight young adults, ranging in age from 19 to 24 years, were recruited as volunteers through flyers posted in colleges and universities around Taoyuan, Taiwan, China. All participants were right-handed, had normal or corrected-to-normal visual acuity with normal color vision, and had no evidence of any neuromuscular disorder. The participants

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