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

Chun-Chih Wang a, Chia-Hao Shih b, Caterina Pesce c, Tai-Fen Song a, Tsung-Min Hung d, Yu-Kai Chang a,⁎

a Graduate Institute of Athletics and Coaching Science, National Taiwan Sport University, Taoyuan County 333, Taiwan, China
b Department of Kinesiology, University of North Carolina at Greensboro, NC, USA
c Department of Movement, Human and Health Sciences, Italian University Sport and Movement, Rome, Italy
d Department of Physical Education, National Taiwan Normal University, Taipei, Taiwan, China

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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).

Keywords: Aerobic exercise; Cognitive control; Executive function; Neuropsychological assessment

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
behavioral assessments and by neuroelectric measurements. Notably, the findings derived from these studies have been mixed; some studies demonstrate facilitative effects of acute exercise and other studies fail to reveal a beneficial effect. 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, executive function is not a simple construct, but is instead an umbrella term that involves a number of subcognitive processes. Some researchers define executive function as including working memory, reasoning, task flexibility, problem-solving, and planning. Other researchers have suggested that executive function involves the sub-cognitive processes of volition, planning, purposeful behavior, and effective performance, or processes that address novelty, planning, and acting on the appropriate strategies for conducting performance. Acute exercise plausibly has a specific influence on certain aspects of executive function. Etnier and Chang 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 Chang 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 WCST has been used extensively to examine frontal cortex function, a brain region that is involved in executive functioning. The WCST has been considered the gold standard of executive function tests 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. Few studies have examined the effects of acute aerobic exercise on executive function using the WCST. Dietrich and Sparling 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 Giorno et al. demonstrated that WCST performance decreased during exercise at two exercise intensities (i.e., ventilatory threshold and 75% ventilatory threshold). Wang et al. 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. Nevertheless, improved WCST performance was observed following acute exercise at moderate intensity in children with attention deficit hyperactivity disorder (ADHD). 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. 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 WSCT 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...
also met the inclusion criteria for health status based upon their responses to a health/medical history questionnaire and the Physical Activity Readiness Questionnaire (PAR-Q) indicating that they could safely perform an acute bout of exercise. After excluding one participant who did not meet the above criteria, 27 participants were included in the study. These processes followed the guidelines of the American College of Sports Medicine for conducting an exercise intervention. The level of physical activity was measured by the International Physical Activity Questionnaire (IPAQ). All participants provided written informed consent that was compliant with the institutional review board at National Taiwan Sport University. The sample size was determined by a power analysis of data from a previous study at National Taiwan Sport University. The sample size was 27 participants with the standard number of 128 cards. The task consisted of four key cards and 128 response cards. The key cards, which were presented in the upper center of the table, were characterized by three relevant categories based on color (i.e., red, green, yellow, and blue), shape (i.e., triangle, star, cross, and circle), or number (i.e., one, two, three, and four). The order of the key cards from left to right was as follows: one red triangle, two green stars, three yellow crosses, and four blue circles. The response cards were located under the key card and on the bottom right of the table. During the test, the participant was instructed to sort each of the response cards according to its characteristics to match one of the four key cards. Although the examiner did not provide instructions prior to or during the performance of the task, feedback of “correct” or “wrong” was verbally presented to the participant to indicate whether the response card corresponded to the key card; thus, the participant used this feedback to determine the next response card. The administration of the task followed the guidelines described in the manual. The task was completed when the entire set of 128 response cards was sorted or six correct categories were achieved (e.g., 10 correctly sorted response cards were consecutively attained). Although no time restriction was set, all participants completed the task within 30 min. Four outcome measures of the WCST described in the manual were included in the analysis: Perseverative Responses (PR), Perseverative Errors (PE), Categories Completed (CC), and Non-Perseverative Errors (NPE).

2.1.5. Laboratory procedure

The participants were asked to visit the laboratory at the National Taiwan Sport University for two individual sessions. In the first session, the participants provided informed consent and were instructed to complete the demographic, health history, PAR-Q, and IPAQ questionnaires. The participants who met the inclusion criteria then wore an HR monitor to record their resting HR, which was assessed as the participants sat quietly in a comfortable chair for 20 min. The eligible participants were then randomly assigned to the exercise group or the reading control group by a computerized number system. In the second session, the participants were administered the WCST as pre-test data. Then, the participants in the exercise group were instructed to perform an acute bout of a cycling ergometer protocol. Alternatively, the participants assigned to the control group were asked to read a book related to physical activity and mental health for a similar amount of time as the exercise group. Finally, the participants were instructed to complete the WCST again as the post-test data. Both sessions lasted approximately 2 h. The participants were briefly informed of the purpose of the research after they completed the entire experimental procedure.
### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study 1 (younger adult)</th>
<th>Study 2 (older adult)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Control group</td>
<td>Exercise group</td>
</tr>
<tr>
<td></td>
<td>Control group</td>
<td>Exercise group</td>
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<tr>
<td>n</td>
<td>13 14</td>
<td>12 12</td>
</tr>
<tr>
<td>Female</td>
<td>11 8</td>
<td>4 6</td>
</tr>
<tr>
<td>Age (year)</td>
<td>22.77 ± 2.39</td>
<td>22.57 ± 2.77</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.07 ± 6.90</td>
<td>166.96 ± 10.68</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.96 ± 13.58</td>
<td>62.14 ± 14.48</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>23.77 ± 3.24</td>
<td>21.25 ± 3.16</td>
</tr>
<tr>
<td>Education</td>
<td>5.14 ± 0.36</td>
<td>5.23 ± 0.44</td>
</tr>
<tr>
<td>IPAQ (METs)</td>
<td>600.40 ± 608.61</td>
<td>1144.01 ± 1229.89</td>
</tr>
<tr>
<td>Resting-HR (bpm)</td>
<td>68.54 ± 9.65</td>
<td>68.14 ± 6.04</td>
</tr>
<tr>
<td>MMSE</td>
<td>— 28.83 ± 1.83</td>
<td>— 29.17 ± 0.75</td>
</tr>
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</table>

Abbreviations: BMI = body mass index; IPAQ = international physical activity questionnaire; Resting-HR = heart rate assessed following participant sat quietly in a comfortable chair for 20 min; MMSE = Mini-Mental State Examination; MET = metabolic equivalent.

### 2.1.6. Statistical analyses

The study was a 2 × 2 mixed design with group as the between-subjects factor and time point as the within-subjects factor. An independent samples \( t \) test or chi-square test, as appropriate, was applied to test the homogeneity of the participants’ characteristics between the two groups, and variables that were significantly different were included as covariates in the analysis. The exercise intensity manipulation was tested based on an analysis of HR using a 2 (groups: exercise, control) × 3 (time points: pre, during, post) mixed analysis of variance (ANOVA). With respect to the WCST, 2 (groups: exercise, control) × 2 (time points: pre-test, post-test) mixed ANOVAs were separately conducted for the four indices. Post-hoc Tukey HSD and follow-up multiple comparisons using \( t \) tests were further performed when a significant main effect for time point in the analysis of HR data or a significant interaction between group and time point in the analysis of HR or WCST was achieved. To avoid the inflation of type I error, Bonferroni adjustments were also applied. The effect size was presented as the partial eta-squared (\( \eta^2 \)) for significant effects. The significance level was set at 0.05 for all analyses prior to the Bonferroni adjustment.

### 2.2. Results and discussion

#### 2.2.1. Participants’ characteristics

The descriptive statistics for the participants’ demographic characteristics are shown in Table 1. There were no significant differences between the control and exercise groups in terms of age, height, weight, body mass index (BMI), IPAQ, and resting HR (\( t < -1.58, p > 0.05 \)), or with respect to gender and education (\( \chi^2 < 2.44, p > 0.05 \)). This suggested similarity between the two groups.

#### 2.2.2. Exercise manipulation check

The 2 × 3 mixed ANOVA revealed main effects for group (\( F = 40.53, p < 0.001, \text{partial } \eta^2 = 0.99 \)) and time point (\( F = 105.93, p < 0.001, \text{partial } \eta^2 = 0.82 \)) as well as an interaction of group by time point (\( F = 94.12, p < 0.001, \text{partial } \eta^2 = 0.80 \)). Simple effects that decomposed the interaction of group by time showed that HR during was highest (116.31 ± 3.16 bpm), followed by HR post (91.15 ± 2.59 bpm) and HR pre (78.76 ± 2.68 bpm). In addition, the exercise group had significantly higher HR during (exercise: 150.49 ± 4.20 bpm; control: 82.64 ± 4.74 bpm) and HR post (exercise: 104.93 ± 3.44 bpm; control: 77.36 ± 3.88 bpm) relative to the control group; no difference between groups was found for HR pre (exercise: 76.42 ± 3.56 bpm; control: 81.09 ± 4.01 bpm). During the exercise period, the participants exercised at 64.6% HRR and reported an RPE of 14.72 on average, suggesting that the exercise was at the desired moderate intensity.

#### 2.2.3. WCST

Table 2 presents the descriptive statistics for the WCST indices separately for the two groups and the two time points.

### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study 1 (younger adult)</th>
<th>Study 2 (older adult)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Exercise group</td>
</tr>
<tr>
<td></td>
<td>Control group</td>
<td>Exercise group</td>
</tr>
<tr>
<td>Factor I</td>
<td></td>
<td></td>
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<tr>
<td>Perseverative responses (PR–)</td>
<td>14.92 ± 20.36</td>
<td>13.43 ± 8.19</td>
</tr>
<tr>
<td>Perseverative errors (PE–)</td>
<td>13.08 ± 15.35</td>
<td>12.21 ± 6.46</td>
</tr>
<tr>
<td>Categories completed (CC+)</td>
<td>5.08 ± 1.80</td>
<td>5.64 ± 0.74</td>
</tr>
<tr>
<td>Factor II</td>
<td></td>
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<tr>
<td>Non-perseverative errors (NPE–)</td>
<td>17.54 ± 19.86</td>
<td>16.14 ± 11.45</td>
</tr>
</tbody>
</table>

Abbreviations: PR = perseverative responses; PE = perseverative errors; CC = categories completed; NPE = non-perseverative errors.

Notes: (+) = higher scores represent better performance; (−) = lower scores represent better performance.
Regarding the PR, a 2 × 2 mixed ANOVA revealed that there was only a main effect for time ($F = 6.74, p = 0.02$, partial $\eta^2 = 0.21$), with a smaller PR in the post-test as compared to the pre-test; no other differences were identified ($F < 0.81, p > 0.05$). For PE, there was also only a main effect for time ($F = 7.80, p = 0.01$, partial $\eta^2 = 0.21$), with a smaller PE in the post-test as compared to the pre-test. The same pattern of pre-to-post error reduction was observed for the NPE ($F = 16.07, p = 0.001$, partial $\eta^2 = 0.39$). Those findings were paralleled, for the CC, by a main effect for time ($F = 6.12, p = 0.02$, partial $\eta^2 = 0.20$), with a higher CC in the post-test as compared to the pre-test. No other significant differences were found (all $p > 0.05$).

The results of Study 1 were unexpected; all indices of the WCST (i.e., PR, PE, CC, and NPE) revealed only time main effects, and no interaction effects with group were identified, thus suggesting that acute exercise failed to demonstrate an effect on executive function as assessed with the WCST. Our findings are inconsistent with previous studies that observed an effect on executive function as assessed with the WCST. Thus, suggesting that acute exercise failed to demonstrate an effect to the pre-test; no other differences were identified ($F < 0.81, p > 0.05$). For PE, there was also only a main effect for time ($F = 7.80, p = 0.01$, partial $\eta^2 = 0.21$), with a smaller PE in the post-test as compared to the pre-test. The same pattern of pre-to-post error reduction was observed for the NPE ($F = 16.07, p = 0.001$, partial $\eta^2 = 0.39$). Those findings were paralleled, for the CC, by a main effect for time ($F = 6.12, p = 0.02$, partial $\eta^2 = 0.20$), with a higher CC in the post-test as compared to the pre-test. No other significant differences were found (all $p > 0.05$).

The results of Study 1 were unexpected; all indices of the WCST (i.e., PR, PE, CC, and NPE) revealed only time main effects, and no interaction effects with group were identified, thus suggesting that acute exercise failed to demonstrate an effect on executive function as assessed with the WCST. Our findings are inconsistent with previous studies that observed a facilitation of WCST performance following exercise. The WCST may not be a sufficiently sensitive measure to show acute exercise effects on executive function of young adults, given that the facilitation was instead observed for individuals with lower executive function performances (i.e., children with ADHD). Young adults who presumably are at their cognitive performance peak may exhibit a ceiling effect that prevents the observation of acute exercise effects. Therefore, we attempted to reproduce the experiment with healthy late middle-aged adults who have probably already experienced age-related cognitive decline to some extent. Cognitive function declines with the aging process, even without signs of pathology. Importantly, performance on executive tasks shows greater age-related reductions compared with non-executive tasks. Previous studies have shown evidence that acute exercise has beneficial effects on executive function in older adults and middle-aged adults. More importantly, a meta-analytic review demonstrated that individuals with lower cognitive status, such as older adults and clinical populations, have larger positive effect sizes than the normal population, which implies that individuals with lower cognitive abilities may benefit from acute exercise to a larger extent. Therefore, the purpose of Study 2 was to re-examine the effects of acute exercise on the WCST with a focus on late middle-aged adults to look for age differences in acute exercise effects on WCST performance and for a potential ceiling effect in the young adult sample. We hypothesized that acute exercise would facilitate WCST performance in this older population.

3. Study 2

3.1. Methods

3.1.1. Participants

Twenty-four late middle-aged adults between 50 and 65 years were recruited as volunteers through flyers posted in a local hospital and communities around Taoyuan, Taiwan, China. The inclusion criteria and recruitment processes were similar to those in Study 1, except that the Mini-Mental State Examination was also administered to control for the mental status of this older age group.

3.1.2. Laboratory process

The exercise protocol, its related measures, and the laboratory procedure were the same as those in Study 1.

3.1.3. Statistical analyses

As in Study 1, an independent samples t test or chi-square test, as appropriate, was first applied to test the homogeneity of the participants’ characteristics between the two groups, and significant variables were included as covariates in the following analysis. Then, a 2 (groups: exercise, control) × 3 (time points: pre, during, post) mixed analysis of variance (ANOVA) was conducted for the four indices of the WCST. Post-hoc Tukey HSD and follow-up multiple comparisons (t tests) were further performed when a significant main effect for time point in the analysis of HR data or a significant group by time point interaction for HR or WCST data was achieved.

3.2. Results and discussion

3.2.1. Participants’ characteristics

Table 1 presents the descriptive data for the demographic characteristics of the late middle-aged participants. There were no significant differences between the control and exercise groups in terms of age, height, weight, BMI, IPAQ, or resting HR ($t < 0.95, p > 0.05$) or in gender or education ($\chi^2 < 0.86, p > 0.05$), which reflects the similarities between the two groups.

3.2.2. Exercise manipulation check

The 2 × 3 mixed ANOVA revealed a main effect for group ($F = 57.09, p < 0.001$, partial $\eta^2 = 0.72$) and time point ($F = 113.40, p < 0.001$, partial $\eta^2 = 0.84$) as well as an interaction of group by time point ($F = 94.98, p < 0.001$, partial $\eta^2 = 0.81$). Simple effects that examined the interaction of group by time showed that HR during was highest (108.90 ± 2.21 bpm), followed by HR post (88.50 ± 2.47 bpm) and HR pre (78.33 ± 9.15 bpm). During the exercise period, the participants exercised at 65.2% HRR and clinical populations, have larger positive effect sizes than the normal population, which implies that individuals with lower cognitive abilities may benefit from acute exercise to a larger extent. Therefore, the purpose of Study 2 was to re-examine the effects of acute exercise on the WCST with a focus on late middle-aged adults to look for age differences in acute exercise effects on WCST performance and for a potential ceiling effect in the young adult sample. We hypothesized that acute exercise would facilitate WCST performance in this older population.

3.2.3. WCST

Table 2 presents the descriptive statistics for the WCST indices separately for the groups and the two time points in the
late middle-aged adult sample. Regarding the PR, no main effects or significant group by time point interaction were found ($F < 1.30, p > 0.05$). Similar to the PR, no significant differences emerged for PE or CC ($F < 1.09, F < 0.54, p > 0.05$). Regarding the NPE, there was only a main effect for time ($F = 4.99, p = 0.036$, partial $\eta^2 = 0.16$), with a smaller NPE at the post-test compared with the pre-test; no other differences were found ($F < 2.43, p > 0.05$).

Thus, the results of Study 2 were similar to those of Study 1, in that no interaction between group and time point was observed for any index of the WCST, which suggests that acute exercise did not influence executive function assessed by the WCST in late middle-aged adults. In addition, except for the NPE, which showed a main effect for time with better performance at the post-test time point, all other indices (i.e., PR, PE, and CC) showed no differences between the pre- and post-test. This indicates that with age increasing, adults may only receive limited benefits from practice or learning.

4. General discussion

The current two investigations aimed to examine the after-effects of acute aerobic exercise on executive function measured by the WCST, which is one of the most commonly used assessment tools for executive function. Regarding the exercise manipulation, both Study 1 and Study 2 revealed an appropriate, moderate level of exercise intensity for the exercise group (mean HR during of 64.6% and 65.2% HRR in younger and late middle-aged adults, respectively) and no baseline difference in HR between the exercise and the control group, as shown by the analysis of HR data.

Notably, the primary findings of Study 1 demonstrated that acute exercise had no influence on any index of WCST performance measured after the cession of exercise. It was supposed that the focus on young adults may have prevented the identification of any facilitative effects of acute aerobic exercise on WCST performance due to the high initial performance and, hence, small room for improvement for young healthy adults. To exclude this potential ceiling effect and look for age-related differences in acute exercise effects on executive function in adulthood, late middle-aged adults (i.e., a population that has probably started experiencing cognitive decline associated with aging) were examined in the subsequent study. Similarly to Study 1, the results of Study 2 did not demonstrate any facilitative after-effects of acute exercise on the indices of the WCST. Taken together, the findings of the two studies therefore suggest that acute aerobic exercise fails to influence executive function as assessed by the WCST.

Our findings contrast with previous studies that, in general, identified beneficial effects on executive function following acute exercise.3,5,7,11–13,15,44–47 The sub-type of executive function examined may be a potential reason for the conflicting results. Miyake et al.48 used a confirmatory factor analysis and demonstrated that executive function involves three distinct sub-components, including mental set shifting (shifting), information updating and monitoring (updating), and the inhibition of prepotent responses (inhibition). Although several exercise and cognition studies have generally demonstrated a facilitative effect on executive function following acute exercise, the majority of studies that associated acute exercise and executive function examined inhibition.11 Notably, the WCST is believed to reflect the shifting aspect of executive function.22,48,49 Specifically, two shifting-related constructs are involved in the WCST. Greve et al.50 indicated that the indices of PR, PE, and CC fall within the construct of “concept formation/perseveration”, which is associated with the ability to shift to a correct sorting principle, and the index of NPE belongs to the construct of “non-perseverative error”, which is related to inefficient or unsuccessful problem-solving during the response to shifting tasks. Although the mechanisms underlying the effects of acute exercise on inhibition and shifting still remain unknown, the results from the acute exercise literature that exercise improves the inhibition,11–13 but has no effect on shifting as observed in the current studies, supports the specificity viewpoint proposed by Etnier and Chang:5 acute exercise may have a specific influence on specific aspects of executive function.

The specificity hypothesis is also supported indirectly by findings from meta-analytic reviews.3,4 Although these reviews indicate that acute exercise has a significant and positive effect on executive function, only a small effect size emerged when considering the global executive function construct that summarized a variety of specific aspects of executive function. Along with the larger effect sizes that are typically observed in empirical studies examining specific aspects of executive function, such as inhibition11–13,15,16,46,47 and planning,6,7,44,51 the findings from these reviews imply that the alterations of sub-components within executive function due to acute exercise are different.

In addition to the potential insensitivity of shifting in response to acute aerobic exercise discussed previously, a further possibility is that the effects of acute exercise on the shifting aspect of executive function are dependent on the specific task utilized. For example, Pesce and Audiffren8 indicated that acute exercise only positively affected switch task performance with more demanding task conditions (e.g., in a cueing paradigm, when the size of the cue and the size of the following target stimulus were mismatched), but not with less demanding task conditions (e.g., when cue and target size were matched). In contrast, Tomporowski et al.7 applied a modified switch task that involved trials of either a single digit (e.g., 1 or 3) or three digits (e.g., 111 or 333) in which the participant was requested to respond based on the instruction of “what number” or “how many”. The results of their study revealed that there was no acute aerobic exercise effect on switch performance. When the Trail Making Test (TMT) was used, which is another neuropsychological assessment tool that measures shifting,39,52,53 acute exercise had no effect on the shifting, but only facilitated inhibition performance assessed by another classical neuropsychological assessment tool, the Stroop Test.45 These results suggest that even when measuring similar features of cognitive function, the type of task may moderate the relationship between acute exercise and executive function.
The brain regions involved in the performance of tasks designed to tap similar executive functions are likely different. When the WCST (i.e., a task involving switch processes), and tasks engaging the inhibition process were compared, a meta-analysis of neuroimaging studies conducted by Buchsbaum et al.\textsuperscript{54} indicated some differences. Although those tasks were generally related to frontoparietal activation, which reflects processes related to executive function, the brain activations during the WCST and the inhibition tasks demonstrated large regional differences, with inhibition processes involved more in the activation of the right prefrontal cortex. It is of interest to note that although the WCST has shown a similar activation pattern as tasks that involve switching processes and therefore is considered to tap the shifting component of executive function, the WCST had a stronger frontoparietal pattern and less involvement of the bilateral ventral and anterior cortices than tests tapping inhibition. These results from the meta-analysis suggest that differences in brain regional activation induced by the specific component of executive function engaged in a given task may explain our findings. Taken together, the results of our two studies provide tentative evidence for the viewpoint by Etnier and Chang\textsuperscript{5} according to which the effects of acute exercise on specific aspects of executive function may be task-dependent.

When comparing the results from the current two studies, also age differences were observable from descriptive statistics. Late middle-aged adults had an obviously worse WCST performance than the younger adults on all four WCST indices (Table 2). This is consistent with previous studies that demonstrated robust age-related changes in the executive function assessed by the WCST.\textsuperscript{49,55–57} For example, Rhodes\textsuperscript{56} conducted a meta-analytic review on age-related differences in performance on the WCST and found robust age differences, particularly with respect to the indices of CC and PE. Importantly, Gamboz et al.\textsuperscript{30} not only observed age-related differences in inhibition, working memory, and global switching, but also indicated that local switching was particularly related to the WCST in older adults, thereby confirming that cognitive aging and shifting are associated with the WCST. Furthermore, an improvement in WCST performance from the first (pre-) to the second (post-) test run was observed in young adults, but was almost absent in late middle-aged adults. This suggests a stronger practice or learning effect in younger adults compared with their late middle-aged counterparts. This finding suggests that the aging process not only decreases executive function, but also is accompanied by a reduction in learning ability. These two age-related observations replicating those presented in the aging literature provide additional support that our WCST results are valid and may be interpreted as absence of acute exercise effects on the WCST.

Several points should be considered when interpreting the findings of the current investigations. Although our sample size was determined by a power analysis, there were few studies that examined the acute exercise effect on the WCST; thus, the effect size was derived from the WCST study conducted by Chang et al.,\textsuperscript{16} which however focused on children with ADHD. A larger sample size may be required to attain an effect for healthy young and late middle-aged adult populations, and therefore, future research is warranted. In addition, although there were no differences in the individual characteristics of the participants assigned to the exercise and control groups, such as age, BMI, IPAQ, or resting HR, other factors may have contributed to the failure to detect an acute exercise effect on executive function. For example, individuals with lower cardiovascular fitness levels or motor coordination skills may benefit from acute exercise to a lesser extent than individuals with higher fitness or motor skill levels.\textsuperscript{58,59} Further examinations of these moderators are warranted to elucidate the complex relationship between acute exercise and executive function. Last, but not least, with the exception of shifting, the WCST involves many aspects of cognitive and executive processes, including working memory\textsuperscript{55,60} and inhibition,\textsuperscript{54} which may have confounded the interpretation of the relationship between acute exercise and the shifting component of executive function tapped by the WCST. Therefore, future studies would be encouraged to use multiple neuropsychological assessments that measure similar specific aspects of executive function simultaneously to explore the relationship between acute aerobic exercise and the sub-components of executive function.

5. Conclusion

To date, few studies have examined the effects of acute exercise on executive function as assessed by the WCST, which is a widely used neuropsychological assessment tool that measures executive function. Therefore, we expanded the existing knowledge base using two studies to investigate the effects of acute aerobic exercise of moderate intensity on WCST performances. Acute exercise failed to significantly influence any indices of the WCST for younger adults and late middle-aged adults. Although unexpected, our findings suggest that the WCST may not be the most sensitive task for detecting acute exercise effects, or the shifting aspect of executive function that the WCST primarily assesses may not be an executive function component that is pronouncedly affected by acute exercise. A failure to identify an acute exercise effect on the WCST supports the perspectives proposed by Etnier and Chang\textsuperscript{5} that the effects of acute exercise on executive function may account for the distinct aspects of execute function that are measured and the specific tasks that are used for assessment.

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