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Effects of acute moderate-intensity exercise on executive function in children with preterm birth: A randomized crossover study

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ABSTRACT

Background: Acute exercise appears to promote executive function (EF) in children. However, the effect of acute exercise on EF in children with preterm birth (PB) remains unclear.
Objective: To investigate whether acute moderate-intensity exercise improves EF in children with PB.
Methods: Twenty child participants with PB (age = 10.95 ± 1.19 years, birth age = 31.71 ± 3.64 weeks) completed exercise and control sessions in a randomized crossover design. In the exercise session, participants completed a 30-minute period of moderate-intensity aerobic exercise. In the control session, participants watched a video for appropriately 30 min. Following each session immediately, inhibitory control, an aspect of EF, was assessed with the Numerical Stroop task.
Results: Response time (RT) for the Stroop's incongruent condition was shorter after the exercise session than after the control session. However, no differences were observed in RT for the congruent condition. Accuracy rate (ACC) in both congruent and incongruent conditions did not differ between exercise and control session.
Conclusion: The findings support the beneficial effect of acute exercise on executive function (EF) in children with PB, particularly in terms of improving inhibitory control.

1. Introduction

Preterm birth (PB) refers to birth before 37 weeks of gestation. PB is a public health issue due to a high incidence of neurodevelopmental impairments during childhood. It is estimated that 40–50 % of PB survivors develop multiple cognitive deficits [1]. These deficits include impaired executive function (EF), an umbrella term describing higher-order cognitive processes responsible for adaptive, goal-directed behavior [2,3]. Importantly, EF impairments for children with PB can persist into adulthood, negatively influencing multiple aspects of life including academic achievement [4,5], social competence [6], and adaptive function [7].

While there is now strong evidence that EF deficits are present in children with PB, yet few interventions for improving EF have been proposed. Acute exercise, also known as a single bout of exercise, has been demonstrated to improve the three core EFs (i.e., inhibitory control, working memory, and cognitive flexibility) in children born full-term [8]. Additionally, studies have also shown EF benefits of acute exercise in overweight children [9] or those with neurodevelopmental impairments such as autism spectrum disorder [10], learning disability [11], and attention deficit hyperactivity disorder (ADHD) [12]. Based on this evidence, it is possible that acute exercise can positively impact EF in children with PB.

Inhibitory control is perhaps the most commonly assessed of the three core EFs [13]. It is the capacity to inhibit disruption from irrelevant stimuli during goal-directed behavior [14]. In comparison to children with born full-term, children with PB exhibit inhibitory control deficits [15–17]. An underlying mechanism of inhibitory control deficits in children with PB is dysfunction of the prefrontal cortex, the activity of which is associated with the ability [18]. Notably, acute exercise has

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been shown to improve inhibitory control by inducing activation in the dorsolateral prefrontal cortex and enhancing performance on tasks related to inhibitory control [19]. Furthermore, a meta-analysis found the beneficial effects of acute exercise on inhibitory control to be heightened in children (effect size for preadolescent children = 0.48) compared to other populations (effect sizes for young adults and older adults = 0.18–0.39) [20]. Taken together, it therefore seems worthwhile to investigate associations between acute exercise and inhibitory control in children, particularly in those with PB.

A key limitation of previous studies that have assessed effects of acute exercise on inhibitory control in children [21–23], is their reliance on a specific task, the Erickson Flanker task. Importantly, other measures are available. The Stroop task, for example, is commonly used to examine inhibitory control in neuropsychological research [24] and also apply it to examine inhibitory control in children population with PB [25] and children with neurodevelopmental disorders [26]. Previously, acute moderate-intensity exercise has been shown to improve Stroop task performance in adults and older samples [27,28]; however, less is known regarding effects in children, and we are not aware of any study that has investigated the effects of acute exercise on Stroop task performance in children with PB.

The aim of this study is to address this knowledge gap by examining whether acute exercise impacts inhibitory control in children with PB. To achieve this aim, we investigate the effects of acute moderate-intensity exercise on inhibitory control assessed with the Stroop task in a sample of children with PB. We thus hypothesize that children of this population who engage in acute exercise show improved EF performance related to inhibitory control.

2. Method

2.1. Participants

We recruited 20 children with PB (14 boys, 6 girls, mean age = 10.95 ± 1.19 years old, mean birth age = 31.71 ± 3.64 weeks). This sample size was sufficient to achieve 80 % statistical power at an alpha level of $p < 0.05$ [29]. Participants and their legal guardians gave informed consent after being given information approved by a government-based Institutional Review Board, before being asked to complete a demographic and health history questionnaire to check for any relevant health problems such as neurological diseases and attentional disorders, and the Physical Activity Readiness Questionnaire (PAR-Q) to ensure that children could participate in a single bout of moderate-intensity exercise [30]. All participants had normal or corrected-to-normal vision and normal intelligence, assessed with the Digit Span task of the Wechsler Intelligence Scale for Children (WISC-R) including forward and backward span [31]. Our protocol followed guidelines of the American College of Sports Medicine [32] and replicated that used in a previous study [12]. The demographic information for all participants was presented in Table 1.

2.2. EF examination

A modified version of the Numerical Stroop task was used to assess inhibitory control [33]. Participants were instructed to view two numbers of different values and font sizes and to decide which was larger in value as quickly as possible. The task involved congruent and incongruent conditions. In the congruent condition, for each pair one number's size and value were larger than the others. In the incongruent condition, numbers with larger values were smaller in size (Fig. 1).

In the process of the Numerical Stroop task, the stimuli were shown at the center of the computer screen with a black background. Fixation signs were presented for 500 ms, before which a pair of numbers appeared and remained in view until the participant responded or 2000 ms had passed. Participants were asked to respond by pressing one of two keys on a keyboard (button 1 if the right stimulus was larger, button 2 if the left stimulus was larger). After each response, the screen was blank for 300 ms before the next stimuli. The task was run using E-Prime version 2 software (Psychology Software Tools Inc.). Both response time (RT) and accuracy rate (ACC) were recorded.

Table 1
Demographic information for all participants (M ± SD).

Variable	Boy	Girl	Total
Sample size (%)	14 (70 %)	6 (30 %)	20
Age (years)	10.86 ± 1.10	11.17 ± 1.47	10.95 ± 1.19
Weight (kg)	33.26 ± 8.50	34.45 ± 9.21	33.62 ± 8.49
Height (cm)	141.79 ± 13.06	143.63 ± 16.12	142.34 ± 13.64
Body Mass Index (kg/m^2)	16.29 ± 2.40	16.47 ± 1.85	16.35 ± 2.20
Birth age (weeks)	31.92 ± 3.72	31.25 ± 3.74	31.71 ± 3.64
Birth weight (g)	1603.92 ± 534.79	1537.00 ± 697.40	1582.79 ± 571.65
Father's education (years)	16.08 ± 1.85	19.33 ± 6.38	17.11 ± 4.00
Mother's education (years)	15.38 ± 1.26	16.67 ± 2.07	15.79 ± 1.62
Digit forward span	13.79 ± 1.97	14.00 ± 0.89	13.85 ± 1.69
Digit backward span	6.43 ± 2.77	7.17 ± 2.04	6.65 ± 2.54
Resting HR	73.64 ± 7.65	78.67 ± 7.71	75.15 ± 7.83

Note. HR = heart rate.

2.3. Physical fitness assessment

Six assessments were conducted to determine participants' physical fitness: 1) cardiovascular fitness was measured by peak oxygen consumption (VO_{2peak}) based on the submaximal exercise test of the YMCA cycle ergometry protocol [34], which has frequently been used in previous studies [35–37]; 2) muscular strength, determined as the highest score on a hand grip dynamometer test whereby participants squeezed a handle three times each with the left and right hand; 3) muscular endurance, assessed by number of abdominal crunches/curl-ups completed in 30 and 60 s; 4) flexibility, measured using the YMCA sit-and-reach test and determined by the distance (cm) between the hamstring and lower back; 5) agility, measured using the *t*-test whereby participants must reach to four corners of a T shape as quickly as possible; and 6) power, assessed by distance (cm) jumped in one standing long jump. The physical fitness information for all participants was presented in Table 2.

2.4. Procedure

Participants visited the laboratory on three separate days at approximately the same time each day with at least 7 days interval between visits. During the first visit, participants and their guardians completed informed consent forms, demographic and health questionnaires, the Digit Span task, and a physical fitness assessment.

During the second and third visits, all participants completed the exercise and control sessions in a randomized crossover counterbalanced order. In the exercise session, participants were instructed to perform moderate-intensity exercise for 30 min. The exercise protocol was designed following ACSM guidelines [32], including a warm-up and cool-down phase of 5 min each and a main exercise of 65–70 % heart rate reserve (HRR) for 20 min [36–38]. In the control session, participants were instructed to watch a video for approximately 30 min. Immediately after each session, the Numerical Stroop task was administered for determining performance related to inhibitory control of EF.

A heart rate (HR) monitor (PolarRS400; Polar Electro) was used to record resting HR at first visit and on several further occasions including during each session and before and after the EF task. We also recorded a rating of perceived exertion (RPE) to assess participants' subjective feeling during exercise session [39].

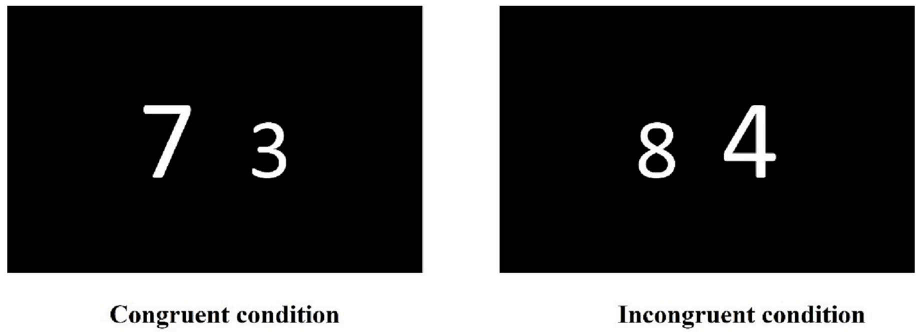

Fig. 1. The two conditions of the Numerical Stroop task.

Table 2
Physical fitness information for all participants (M ± SD).

Variable	Boy (n = 14)	Girl (n = 6)	Total (n = 20)
Cardiovascular fitness/VO2peak (mL/kg^{-1}/min^{-1})	35.96 ± 5.93	35.17 ± 5.42	35.72 ± 5.65
Muscular strength/right hand (kg)	15.96 ± 7.18	15.50 ± 7.29	15.83 ± 7.02
Muscular strength/left hand (kg)	15.86 ± 7.59	13.83 ± 7.22	15.25 ± 7.35
Muscular endurance/push-up for 30 s	14.43 ± 7.90	12.67 ± 5.32	13.90 ± 7.13
Muscular endurance/push-up for 60 s	20.93 ± 10.18	23.17 ± 11.41	21.60 ± 10.31
Flexibility/sit and reach (cm)	20.00 ± 7.51	23.89 ± 3.80	21.17 ± 6.76
Power/long jump (cm)	144.04 ± 18.87	131.00 ± 26.33	140.13 ± 21.53
Agility/*t*-test (second)	14.03 ± 1.97	15.67 ± 2.85	14.54 ± 2.34

2.5. *Statistical analysis*

Data were analyzed using SPSS version 18 (SPSS Inc.). A 2 (session: exercise, control) x 3 (time: during session, before cognitive test, after cognitive test) repeated measures analysis of variance (ANOVA) to determine the effect of acute exercise on HR. Additionally, a 2 (session: exercise, control) x 2 (task condition: congruent, incongruent) ANOVA for determining the difference of RT and ACC for the Numerical Stroop task. Greenhouse-Geisser epsilon corrections were used to address violations of the assumption of sphericity. Post hoc comparisons were made using a familywise alpha level set at 0.05 prior to Bonferroni correction.

3. Results

3.1. *Exercise treatment manipulation*

The two-way ANOVA revealed a significant main effect on HR of session [$F(1,19) = 126.16$, $p = 0.00$, partial eta square = 0.93] and time [$F(2,18) = 78.75$, $p = 0.00$, partial eta square = 0.89], and a significant interaction between session and time [$F(2,18) = 96.39$, $p = 0.00$, partial eta square = 0.91]. Follow-up analysis revealed that HR during the exercise session was significantly higher (153.39 ± 10.79) than before exercise session (100.45 ± 9.76) and after exercise session (92.64 ± 11.39). No significant difference in HR was found at different times during the control session (during control session = 80.84 ± 9.62; before control session = 83.83 ± 13.70, after control session = 88.09 ± 16.62). Mean perceived exertion during the exercise session was 15.17 ± 1.65, confirming that exercise was in the moderate-intensity range (score of 14 to 17) [32].

3.2. *Numerical Stroop task performance*

3.2.1. *Response time*

The two-way ANOVA for RT revealed a significant main effect of session [$F(1,19) = 9.42$, $p = 0.01$, $\eta_p^2 = 0.33$]. RT was shorter following the exercise session than the control session (608.90 ± 30.62 vs. 657.90 ± 34.54 ms). There was also a main effect of task condition [$F(1,19) = 104.03$, $p = 0.00$, $\eta_p^2 = 0.85$], with RT shorter in the incongruent condition than in the congruent condition (678.22 ± 32.60 vs. 588.58 ± 31.29 ms).

There was a significant interaction between session and time [$F(1,19) = 4.12$, $p < 0.05$, $\eta_p^2 = 0.18$]. Follow-up analysis showed that RT for the incongruent condition were shorter following the exercise session than following the control session ($p = 0.00$; 643.31 ± 142.13 vs. 713.14 ± 160.65), while there was no significant difference in RT for the congruent condition between exercise and control sessions ($p = 0.16$) (Fig. 2).

3.2.2. *Accuracy rate*

The two-way ANOVA for ACC revealed a significant main effect of condition [$F(1,19) = 36.81$, $p = 0.00$, $\eta_p^2 = 0.66$], with higher ACC in the congruent condition than the incongruent condition (0.95 ± 0.01 vs. 0.84 ± 0.02). There was no significant main effect of session on ACC [$F(1,19) = 0.30$, $p = 0.59$] and no significant interaction between session and task condition [$F(1,19) = 0.36$, $p = 0.55$].

4. Discussion

This study assessed the effect of acute moderate-intensity exercise on inhibitory control assessed with the Numerical Stroop task in a sample of children with PB. We found that RT of the Stroop's incongruent condition, an ability of inhibitory control, were faster after an exercise session than after a control session. This difference was not found for the Stroop's congruent condition, which assesses selective attention and basic information processing. In addition, there were no significant differences in ACC between exercise and control sessions. These findings imply that acute exercise may facilitate inhibitory control, but the selective attention and information processing speed is insensitive for children with PB.

The Numerical Stroop task has been widely used as a measure of multiple cognitive abilities including selective attention, information processing speed, and inhibitory control [40–42]. Performance in the Stroop's incongruent condition is thought to reflect the ability to inhibit automatic responses to stimuli. Typically, RT is slower and ACC is poorer in the incongruent than in the congruent condition, a phenomenon known as the *Stroop effect* [43]. Similarly, we observed the Stroop effect in our finding, meaning the task is suitable to determining the inhibitory control in the children with PB. Importantly, while the present study did not compare Numerical Stroop performance of children with PB and children born full-term, Direk, Makharoblidze [44] reported that children with PB showed slower RT on the Stroop task than those born full-

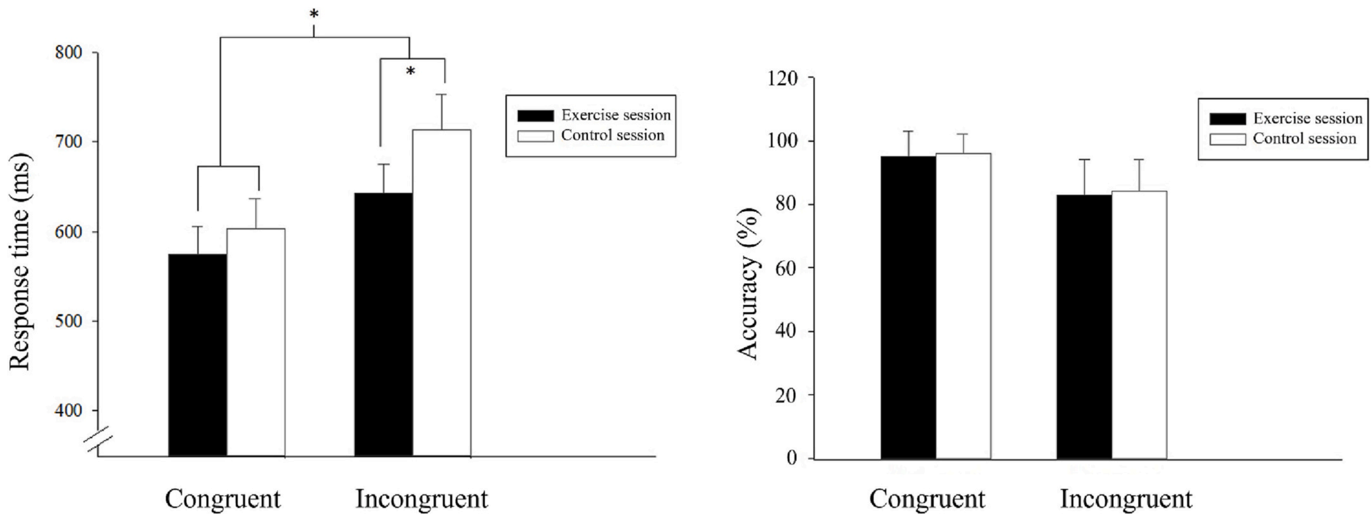

Fig. 2. The Numerical Stroop task performance stratified by exercise and control sessions.
Note: * indicates a significance difference ($p < 0.05$).

term, indicating that the Stroop task is sensitive to differences in performance between these two populations.

To the best of our knowledge, this is the first study to examine the effects of acute exercise on EF in children with PB. Our findings indicate a positive relationship between acute exercise and inhibitory control, which is in line with previous studies with young adult and preadolescent children [45,46]. Sibley and colleagues (2006), for example, found that young adults' performance on the Stroop Color-Word task improved after a single bout of exercise. Similarly, Chu, Kramer [46] reported that moderate-intensity aerobic exercise for 30 min improved RT on the incongruent condition of the Stroop Color-Word task in both preadolescent children and young adults. Despite no previous studies used Numerical Stroop task that the present study focused on, results of the current study replicate these earlier findings and add to current knowledge by demonstrating that moderate-intensity exercise facilitates inhibitory control in children with PB.

We found that faster RT on the Stroop task following acute exercise was limited to the incongruent condition, which was expected and in agreement with previous findings. Specifically, Chang, Liu [12] studied participants with ADHD and found that acute moderate-intensity exercise facilitated performance in the incongruent condition of the Stroop task but not the congruent condition. Cooper, Dring [47] also showed that a single bout of games-based activity enhanced RT only in the incongruent condition of the Stroop task, both immediately after and 45 minutes post-exercise, suggesting some degree of sustained effect. The present study did not assess length of effect, though we recommend that future studies focus on immediate and sustained impacts.

Acute exercise did not significantly alter ACC of Stroop task in this study, indicating that improvements brought by acute exercise only apply to faster RT and that these do not result from a speed-accuracy trade-off. This finding is somewhat inconsistent with findings from previous studies that have examined effects of acute exercise on inhibitory control, which did show improvements in ACC [48,49]. The inconsistency could be attributed to differences in the EF examination and targeted population. Specifically, Hillman, Pontifex [49] and Drollette, Shishido [48] used a modified Flanker task to assess inhibitory control (Flanker task vs. Numerical Stroop task) and their studies mainly focus on children born full-term (children born full-term vs. children born preterm). However, this is first time to investigate the effect of acute exercise on inhibitory control in children with PB, so more studies are needed to further ensure its causal relationship.

The mechanisms explaining why acute exercise would improve inhibitory control in children with PB are not yet known. One underlying mechanism is through neuroelectric adjustment. For instance, Drollette, Scudder [23] investigated the effects of acute exercise on EF using a modified flanker task and assessed event-related potentials (ERP). Findings revealed that preadolescent children showed improved performance following moderate-intensity walking as well as smaller N2 amplitude and shorter P3 latency in response to task stimuli, implying that acute exercise facilitates the ability to manage response conflict and improves speed of stimulus classification. Similar findings have been reported in children with ADHD [50], with children displaying better performance and faster processing on neuroelectric indices after 30 min of moderate-intensity exercise. Another possible mechanism might be exercise-induced brain-derived neurotrophic factor (BDNF), an important biomarker related to EF [51] and brain facilitation [52]. Previous studies have shown that exercise can increase BDNF levels [53,54] or enhance the link between BDNF level and inhibitory control performance on the Stroop task, both during and after acute exercise [55]. To date, a few studies have focus on this issue regarding acute exercise and BDNF and some studies failed to find such a link [38,56] or suggested that repeated acute exercise may have accumulative EF benefits [57], so future research is recommended to further ensure its mechanism of acute exercise and EF.

Several limitations of the current study should be acknowledged. The first is the relatively small sample size. Although the present study achieved statistical power of 80 %, a larger sample size could more firmly establish a causal relationship between acute exercise and inhibitory control in children with PB. Second, assessment of inhibitory control focused only behavioral performance, meaning we were not able to examine any mechanism of effect. Future studies could extend our work by employing neuroimaging measures such as electroencephalogram or magnetic reasoning imaging to advance understanding of the relationship between acute exercise and EF. Third, although the present study used randomized crossover design to explore the effects of acute exercise on inhibitory control, future studies using randomized control trials is warranted to further ensure its relationship in children with PB. Finally, we did not measure possible moderators of the link between acute exercise and inhibitory control. Previous studies have shown that physical fitness [27,37,58] and socioeconomic status [59] may affect improvement of EF following acute exercise, so future studies should explore these possibilities.

5. Conclusion

This study highlighted that a single bout of exercise can improve EF in children with PB. Specifically, acute moderate-intensity exercise facilitated faster RT on the Stroop's incongruent condition, implying that exercise can improve inhibitory control in this population. The possible explanation is that exercise enhances the ability to process response conflict and speed of stimulus classification. Knowledge of the relationship between acute exercise and EF in children with PB is still limited, however, meaning further investigation is warranted.

Author statement

The authors report no potential conflict of interest. In addition, this manuscript represents results of the literature by our own work and will not be submitted for publication elsewhere until a decision is made regarding its acceptability for publication in the *Early Human Development*. If accepted for publication, it will not be published elsewhere. Furthermore, there were no any perceived financial conflicts of interest related to the research reported in the manuscript.

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Ethical approval

The authors assert this work complies with the ethical standards approved by the institutional review board.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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