Effects of acute aerobic exercise on response preparation in a Go/No Go Task in children with ADHD: An ERP study

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Abstract

Purpose: The purpose of this study was to investigate the impact of acute exercise on reaction time and response preparation during a Go/No Go Task in children with attention deficit hyperactivity disorder (ADHD).

Methods: Nineteen children with ADHD (aged between 8 and 12 years old) undertook a 30-min intervention that consisted of treadmill running or video-watching presented in a counterbalanced order on different days. A Go/No Go Task was administered after exercise or video-watching.

Results: The results indicated a shorter reaction time and smaller contingent negative variation (CNV) 2 amplitude following exercise relative to the video-watching. For event related potential (ERP) analyses, greater CNV 1 and CNV 2 amplitudes in response to No Go stimuli in comparison to Go stimuli was observed in the video-watching session only.

Conclusion: These findings suggest that acute exercise may benefit children with ADHD by developing appropriate response preparation, particularly in maintaining a stable motor preparatory set prior to performing the given task.

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Keywords: Attention deficit hyperactivity disorder; Attention orienting; Contingent negative variation; Cognition; Physical activity

1. Introduction

Attention deficit hyperactivity disorder (ADHD), characterized by age-inappropriate symptoms of hyperactivity, inattentiveness, and impulsivity,1,2 is one of the most common developmental disorders, affecting approximately 5% of school-age children.3 Converging evidence from imaging and neuropsychological studies points to impaired inhibitory control as a fundamental deficit in those with ADHD, implying that response inhibition mediates functional deficits that underlie ADHD symptoms.4 Additionally, studies have shown that individuals with ADHD have difficulties in deliberately inhibiting dominant, automatic, or prepotent responses, leading to impairment in motor control and impulsive behavior.

Effective medications ameliorate symptoms in the ADHD population through their influence on specific neurotransmitter systems such as the norepinephrine (NE) and dopamine (DA) systems.5 Catecholamines are also implicated in ADHD-associated fronto-subcortical circuits (lateral prefrontal cortex, dorsal anterior cingulate cortex, caudate, and putamen) and serve as potential mechanisms underlying the activation of medication treating ADHD. For example, treatment of Methylphenidate (MPH), a catecholamine reuptake inhibitor, is believed to help by increasing DA signaling through multiple actions, including blockade of the DA reuptake transporter, amplification of DA response duration, disinhibition of the dopamine D2 receptor, and amplification of DA tone.6 Notably, stimulant medication not only results in positive effects on the clinical symptoms of ADHD and inhibition, but also improves other cognitive abilities including response...
speed and accuracy,\(^7\) response variability, and response re-engagement.\(^8\)

Acute exercise may exert similar impacts as that of medication on inhibitory control in the ADHD population. Based on Cooper’s\(^9\) assertion that acute exercise increases brain concentrations of catecholamine neurotransmitters DA and NE, Tantillo et al.\(^10\) used indirect measures (i.e., spontaneous eye blink rates and acoustic startle eye blink response) to assess dopaminergic response to acute exercise in children with ADHD and suggested that cerebral DA levels increased following a single session of exercise. Several studies also found an augmentation in serotonin, DA, and NE after a short period of exercise in healthy rats and in humans.\(^11,12\) Given that DA and NE are highly involved in activations in anterior cingulate cortex (ACC) and prefrontal cortex (PFC),\(^13\) the cortical areas which play important roles in the inhibition of prepotent response,\(^14\) this elevated activation suggests that acute exercise may positively regulate inhibition control in children with ADHD. Indeed, recent studies have indicated that a single bout of moderate intensity aerobic exercise benefits inhibition-related executive function in ADHD children.\(^15,16\) Chang and colleagues\(^15\) showed that children with ADHD performed better on the Stroop Color-Word Task after a single 30-min bout of aerobic exercise, highlighting the positive effect of acute exercise on interference control in children with ADHD. Additionally, Pontifex et al.\(^16\) examined event related potentials (ERPs) associated with the regulation of executive control from electroencephalogram (EEG) recordings and suggested that children with ADHD exhibit enhancement in inhibitory control and allocation of attentional resources, coupled with selective enhancement in stimulus classification and processing speed, following a single 20-min bout of moderate-intensity aerobic exercise.

Although several studies have examined the effects of acute exercise on the ADHD population, studies regarding acute effects on the inhibitory process in the ADHD population are primarily concerned with cognitive inhibition, or inhibiting stimuli that are irrelevant.\(^17\) ADHD has been linked to both cognitive and motor inhibition\(^18\) and the impairment of executive motor inhibition is believed to be the core deficit in ADHD.\(^19\) Whether the beneficial effects of exercise can be extended to this subcomponent of inhibitory processes remains unknown. Therefore, this study attempted to focus on the effects of a single bout of aerobic exercise on executive motor inhibition, assessed by an inhibitory Go/No Go Task, in children with ADHD.

Contingent negative variation (CNV) is one of the most commonly studied EEG markers of preparatory activity.\(^19\) The CNV reflects a tonic modulation of the EEG signal in the preparatory period between a warning (S1) and an imperative (S2) stimulus, which represents processes involved in the preparation for signaled movements.\(^20\) CNV can be assessed in a Go/No Go paradigm where the S1 serves as a warning signal for the participant to prepare for the coming imperative stimulus (i.e., S2), and the S2 signals either that a response should be given when a Go is presented or that a response should be held when a No Go appears. In healthy subjects, a negative slow wave is elicited in both Go and No Go trials, but the CNV amplitude is typically increased in conditions requiring a response to the S2 versus a condition not requiring a response to the S2.\(^21\) With sufficiently long inter-stimulus intervals, two components can be distinguished: CNV 1 (also known as early CNV or O-wave) and CNV 2 (also known as late CNV or E-wave).\(^22\) The CNV 1 is believed to index both an orienting response to the S1\(^22\) and stimulus processing or evaluation of the cognitive information contained in the S1.\(^23\) The CNV 2 is considered to be an index of anticipatory attention for the upcoming stimulus and motor preparation needed to respond to it.\(^24\) It has been suggested that the CNV 1 reflects a preactivation of the neural resources that are needed for sensory analysis and response to the S2\(^23\) as well as being considered a correlate of controlled, attentional effort during the expectancy period.\(^25\)

Children with ADHD show lower CNV amplitude when compared to non-ADHD children (ages: 8–14 years) in a Go/No Go Task. For example, early research reported reduced CNV in children with concentration problems.\(^26\) Later investigations have also shown similar results such that an attenuated CNV 1,\(^27\) and a reduced frontal-central CNV 2 have been observed in children with ADHD.\(^28\) Moreover, Johnstone and Clarke\(^29\) revealed a reduced CNV 2 across the midline for ADHD inattentive subtype and across the central region for ADHD combined subtype, suggesting a deficiency in energy pools that points specifically to reduced effort to meet task demands.\(^30\)

The CNV has been shown to be influenced by acute exercise. Kamijo et al.\(^31\) found that acute exercise at moderate intensity elicited larger CNV 1 and CNV 2 amplitudes compared to high intensity exercise. Given that the early CNV is related to attentional orienting\(^22\) and the late CNV is related to motor preparation,\(^24\) this observation suggests that acute exercise at moderate intensity enhances these aspects of cognition and that moderate intensity exercise is beneficial to cognitive functioning.

To date, only a few studies have examined acute exercise effects on motor inhibition using CNV in the general population and exercise effects in the ADHD population remain unknown. The aim of the present investigation was to examine the impact of acute exercise on Go/No Go Task performance and the CNV component in children with ADHD to further our knowledge in terms of the effect of acute exercise on the motor preparatory processes of behavioral inhibition in this population. Given that the CNV is thought to be specifically related to attention orientation and response preparation, it is expected that acute exercise of moderate intensity would lead to better performance in inhibition control tasks, accompanied by greater CNV amplitude in children with ADHD.

2. Methods

2.1. Participants

We recruited 19 children with ADHD between the ages of 8 and 12 years via flyers. The participants were included if they
met the following inclusion criteria: (1) ADHD-classified as diagnosed by a psychiatric physician; (2) reported as being free of comorbid conditions, intellectual disability, brain injury, and neurological diseases; (3) had self-reported normal or corrected-to-normal eyesight; (4) right-handed; and (5) free of physical disability. Three participants were excluded from ERP analysis due to contaminated EEG data. All participants were from families of middle to higher-middle socioeconomic status. According to the participants’ information (Table 1), psychostimulants, such as MPH, were the most commonly used medication among the participants. In pharmacokinetic studies involving children, immediate-release MPH peak serum drug levels are achieved at 2 h after dosing, typically lasting only to 4 h. Even long-acting medications, such as Concerta, can only provide efficacy for approximately 12 h after dose administration. For the sake of avoiding influences from medication in this study, it was mandatory for medication to be discontinued for 24 h before testing took place to allow for complete wash-out. The study was approved by Taipei Medical University–Joint Institutional Review Board. Assent was obtained from the children and written informed consent from their guardians.

2.2. Cognitive task

Motor inhibition was measured by the Go/No Go paradigm which requires participants to respond to one of two choices but withhold a response to the other alternative. The study adopted a modified version of the Go/No Go Task, including a visual warning stimulus (S1, 500 ms), which was a yellow, square-shaped, geometrical signal that was then followed by either a green, circular-shaped geometrical signal (S2), upon which the participants had to press a button (Go), or a red, pentagon-shaped geometrical signal (S2), which required the participants to withhold their response (No Go). The S1–S2 interval was set at a constant of 2000 ms and the inter-trial interval was set at 1500 ms. Seventy-five percent of trials were Go trials, and the order of Go and No Go stimuli was randomized. Twenty practice trials were presented, followed by an experimental set of five blocks of 40 trials each. Participants were instructed that the warning stimulus cued them for the second stimulus and that they were to then press a button as quickly as possible only to the Go stimulus. All participants responded with their right index finger.

2.3. Procedure

The study was performed as a randomized cross-over design that required participants to make two visits to the lab over an interval of 7 days. In the first visit, participants were familiarized with the testing procedure as well as the laboratory, and written informed consent, health and demographics questionnaires were provided to the accompanying adults. Participants were then tested on the Movement Assessment Battery for Children (Movement ABC). Once the measurements were completed, participants were then fitted with a lycra electrode cap, and impedances and the quality of the EEG signal were checked. At the beginning of the experiment, a 1-min resting eye-opened EEG, 1-min resting eye-closed EEG, and 1-min resting heart rate (HR) were recorded. Participants then underwent either the aerobic exercise or the video-watching session. About 5 min after a 30-min treadmill exercise/30-min video-watching (to allow for HR returning to resting state after the exercise), all the participants completed measures of the Go/No Go Task.

On the day of the second visit, the participants underwent a different intervention from the first visit. They were required to either watch exercise videos or complete a moderate-intensity aerobic exercise for 30 min and the Go/No Go Task was then performed following the same procedure as that of the first visit. Following the completion of Go/No Go Task, the participants and guardians were briefed on the purpose of the experiment.

2.4. Acute exercise session

The exercise intervention followed that used previously by Chang et al. A 30-min moderate-intensity aerobic exercise session was conducted on treadmill including a 5-min warm-up and a 5-min cool-down. The speed of the treadmill was gradually increased to meet the goal of reaching the target HR within 5-min. After the warm-up, participants ran at target HR which was set at 60% of HR reserve (HRR). HRR was calculated as maximal HR (HRmax) minus resting HR. The HRmax was estimated using an indirect formula “206.9 − 0.67 × age” and the target HR was calculated by a formula as follows:

$$\text{Target HR} = (\text{HR}_{\text{max}} - \text{resting HR}) \times \text{percentage intensity desired} + \text{resting HR}$$
To monitor the exercise intensity, participants were required to wear a Polar watch (Polar RS800CX; Polar Electro Oy, Kempele, Finland) and have their HR tracked every 2 min during exercise. The velocity was slightly modified based on the HR.

2.5. EEG recording and ERP extraction

EEGs were recorded by NeuroScan NuAmps acquisition amplifiers (Neuroscan, Charlotte, NC, USA). An electrode cap was placed according to the 10–20 International System. The signals were recorded from 15 sites (Fz, F3, F4, FCz, FC3, FC4, Cz, C3, C4, CPz, CP3, CP4, Pz, P3, and P4), which were all referenced to linked earlobes, where Fpz served as the ground electrode. Additionally, vertical and horizontal eye movement artifacts (VEOG and HEOG, respectively) were assessed through the collection of bipolar electro-oculographic activity (EOG). A 60-Hz notch filter was also employed during the data collection process, and the bandpass of the filter was set between 1 and 100 Hz. Scalp electrode impedances were below 10 kΩ. Data were acquired at a sampling rate of 500 Hz using Neuroscan software.

The ERP data were off-line processed with Scan 4.3 software (Compumedics USA, Ltd., El Paso, TX, USA). Epochs of 2000 ms before S2 onset were computed with an additional 200 ms pre-stimulus (S1) baseline. EEG signals that were contaminated by EOG were corrected using an algorithm. In addition, trials with amplitude excursions exceeding ±100 μV were excluded and then data were filtered with a 30-Hz low-pass cutoff (24 dB/octave). All trials were finally averaged for both Go and No Go conditions separately following visual inspection for artifacts.

Grand average ERP waveforms for each session and stimulus type were displayed for the purpose of identifying each component’s latency range. CNV 1 and CNV 2 were quantified by determining the mean amplitude in the range 300–600 ms and 1700–2000 ms after the warning stimulus (S1) onset, respectively.

2.6. Data analysis

Performance measures were reaction time (RT), hit (correct responses to Go stimuli), commission errors (responses to No-Go stimuli), and omission errors (failure to respond to Go stimuli). All error trials or trials with responses that were faster than 200 ms or slower than 1000 ms (<2% of trials) were considered anticipation errors or failures to respond, respectively. These were equally distributed across sessions and were discarded from RT analysis. The hits, commission errors, and omission errors were converted to a percentage of total trials.

For comparing the different influences of exercise and video-watching on task performance, the RT, hit rate, commission error rate, and omission error rate were subjected to paired t tests. For analyses of CNV, repeated-measures analyses of variance (ANOVAs) were used to analyze mean amplitude with session (exercise/video-watching), stimulus (Go/No Go), and region (Frontal/Frontocentral/Central/Parietal/Centroparietal) as within-subject factors. Regions were created by averaging activity across several sites (Frontal = F3, F4, Fz; Frontocentral = FC3, FC4, FCz; Central = C3, C4, Cz; Centroparietal = CP3, CP4, CPz; Parietal = P3, P4, Pz) in the Go/No Go Task. Data were processed by the SPSS software (Version 20 for Windows; IBM Co., Chicago, IL, USA), with the α level set to 0.05.

3. Results

3.1. Task performance

Table 2 provides the means and SD for behavior variables in the Go/No Go Task.

Within the Go/No Go Task, paired t tests revealed a significant difference in RT (\( t(18) = -2.230, p = 0.039, d = 0.236 \)). The result showed that the mean RT for Go stimuli was shorter in the exercise session than that in the video-watching session. No differences in terms of hit rate, omission error rate, or commission error rate were revealed between exercise and video-watching sessions.

3.2. CNV measures

The CNV 1 amplitude analyses revealed significant main effects for region (\( F(4, 60) = 14.30, p < 0.001 \), partial \( \eta^2 = 0.49 \)). Post hoc analyses indicated that the CNV 1 amplitude was the smallest at the parietal area (all \( p < 0.05 \)), and the CNV 1 amplitudes gradually increased from posterior areas to anterior areas (parietal < centro-parietal < central < fronto-central < frontal). All the comparisons were significant (all \( p < 0.05 \)), except for the comparison between the frontal area and fronto-central area (\( p = 0.328 \)). Analyses of the CNV 1 amplitude revealed no significant three-way interaction (\( F(4, 60) = 2.08, p = 0.095; \eta^2 = 0.12 \)), but a significant interaction of Session by Stimulus (\( F(1, 15) = 4.62, p = 0.048; \eta^2 = 0.24 \)). Further testing showed no difference between No Go and Go stimuli in the exercise session, but a significantly larger CNV 1 amplitude for the No Go stimulus than for the Go stimulus in the video-watching session, \( t(15) = 2.59, p = 0.020, d = 0.06 \) (Fig. 1).

As for CNV 2 amplitude, ANOVA for the mean amplitude failed to show any significant main effects. However, an interaction of Session by Stimulus by Region was revealed (\( F(4, 60) = 4.49, p = 0.003; \eta^2 = 0.23 \)). A decomposition of this interaction yielded a significant interaction of

<table>
<thead>
<tr>
<th>Task performance measures for each session (mean ± SD).</th>
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<tbody>
<tr>
<td><strong>Session</strong></td>
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<tr>
<td><strong>Exercise</strong></td>
</tr>
<tr>
<td>Reaction time (ms)</td>
</tr>
<tr>
<td>Hit rate (%)</td>
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<tr>
<td>Omission error rate (%)</td>
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<tr>
<td>Commission error rate (%)</td>
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<tr>
<td><strong>Video-watching</strong></td>
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<tr>
<td>Hit rate (%)</td>
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<tr>
<td>Omission error rate (%)</td>
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<td>Commission error rate (%)</td>
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Note: *p < 0.05, compared with video-watching session.
Session and Stimulus in the frontal area ($F(1, 15) = 4.58$, $p = 0.049; \eta^2 = 0.23$). Follow-up analyses showed a significantly smaller frontal CNV 2 amplitude on No Go stimulus after exercise than for the video-watching session ($t(15) = 2.14$, $p = 0.049$, $d = 0.69$). In addition, there was no difference between the No Go and Go stimuli in the exercise session; however, a larger frontal CNV 2 amplitude for the No Go stimulus compared to the Go stimulus in the video-watching session ($t(15) = 2.41$, $p = 0.028$, $d = 0.42$).

4. Discussion

The main purpose of this study was to explore the effects of a single bout of treadmill exercise on attention orienting and response preparation in children with ADHD. The results revealed that participants with ADHD displayed a shorter RT in response to Go stimulus and a smaller frontal CNV 2 amplitude for No Go stimulus in the exercise than the video-watching session. Additionally, greater CNV 1 and frontal CNV 2 amplitudes for No Go stimulus compared to the Go stimulus were observed in the video-watching session only.

A shorter RT in the Go/No Go Task immediately following exercise was revealed in children with ADHD, and such an accelerated response to task stimuli is consistent with previous findings, providing evidence for the benefits of acute exercise in the ADHD population. The Go/No Go Task is a forced-discriminative RT task that demands rapid responses to Go signals while inhibiting prepotent responses to No Go signals that are administered in a state of uncertainty, making it ideal to assess the processes of behavioral impulsivity. Performance on this task is linked with the decision process, i.e., activation or suppression of the motor response after comparison of the transduced stimulus with an internal representation. Hence, one possible explanation of the results of this study is that participants made altered the speed-accuracy trade off following the exercise session. There is evidence from other studies that individuals who are more deliberate in identifying the appropriate response show a longer RT in the Go/No Go Task with a loss of speed in decision-making. However, if the shorter RT in this study was a result of producing quicker decisions by sacrificing accuracy, more commission errors should have been made after exercise as compared to after the video session and this was not the case. Results of the current study showed no significant difference in commission error rates between exercise and video-watching, indicating that the speed-accuracy trade off could not explain the shorter RT observed following acute exercise.

It has been proposed that arousal alteration is a potential underlying mechanism of acute exercise and cognitive performance. The regulation of arousal by acute exercise is particularly relevant to children with ADHD as recent theories suggest that effort, arousal, and activation are the three cognitive energetic pools associated with information processing, and ADHD may be related to energetic state deregulation. Similarly, Halperin and Schulz implicated early damage to several subcortical regions that mediate arousal and alerting, including the locus coeruleus and the reticular formation, as possible etiologic factors in ADHD. According to the hypoarousal hypothesis, the inattention and hyperactivity in ADHD are a result of cortical underarousal. Some medications, such as MPH, are believed to improve ADHD symptoms by increasing arousal and alertness of the central nervous system through stimulation of the NA and DA systems. Thus, physical exercise feasibly modulates intrinsic brain activation systems, which expands the basic energy available for information processing (e.g., “cognitive-energetic” approaches). It is probable that a homeostatic cascade of neuroendocrine adaptations (both in the periphery and in the brain) mediate these modulating effects that eventually increase ascending reticular activation system (ARAS) transmitter release, especially for DA and NE.

As for the ERP results, a smaller frontal CNV 2 amplitude for the No Go stimulus was found in the exercise compared to the video-watching session. The late phase of the CNV represents activation of the supplementary motor and premotor areas and is believed to reflect motor preparation processing, including postural preparation and anticipatory...
attention directed to the S2. For the ADHD population, CNV is attenuated while executing S1–S2 tasks, representing impaired resource allocation during the preparatory stage. Accordingly, a smaller CNV 2 observed in our study may imply lower activation in motor pathway or reduced involvement of motor preparation and would have been expected to lead to poorer performance, especially in commission errors. However, again, there was no difference in commission error revealed between the two sessions and quicker responses to Go stimuli were found after exercise. Thus, the smaller CNV 2 amplitude post-exercise may reflect an applicable motor preparing strategy to deal with the demands of Go/No Go Task for ADHD children. Successful inhibition of movement when the No Go stimulus appeared may be the result of fewer resources invested in anticipation after exercise. Future research will be necessary to confirm the accuracy of this interpretation of the CNV 2 data.

Our results also demonstrated that larger CNV 1 and frontal CNV 2 amplitudes were observed for the No Go stimulus compared to the Go stimulus in the video-watching session. Smith et al. adopted a modified Go/No Go Task with informative cues to induce varying levels of response preparation. They observed that CNV amplitude increased with the likelihood of making a specific/definite overt response, suggesting that participants prepared responses according to the prediction of the cue. In the present study design, although the S1 provided no information about the target (S2), the larger number of Go trials involved build-up of a significant prepotent response level and led to preference for response-making preparation throughout the task. CNV amplitude increases in the frontal area when greater amounts of cognitive control are required to act correctly within the stimulus environment or when an increase in resource allocation is required by effortful demands associated with task instruction (i.e., speed instructions). Collectively, increased CNV 1 and frontal CNV 2 amplitude for No Go stimulus was associated with the necessity of allocating a greater amount of cognitive control. Interestingly, the CNV amplitude differences between No Go and Go stimuli were not present in the acute exercise session; that is, the allocation cognitive control in No Go stimulus was similar to Go stimulus in the exercise session. These findings suggest that exercise may enhance the maintenance of a stable motor preparatory set and, essentially, children with ADHD were able to allocate constant mental resources to the given task after conducting exercise.

Some limitations in the current study should be acknowledged. First, the overall hit rate was rather high in the present experiment, which indicated that the Go/No Go Task might have been rather easy to perform for the participants. It would be preferable to increase task difficulty in future studies to further assess the contribution of acute exercise in motor inhibition for children with ADHD. In addition, the recruited participants in this study included three subtypes, and medication use was diverse among participants. This may potentially have influenced the results. In future research, the subtype of ADHD and medication use should be taken into account while recruiting.

5. Conclusion

To summarize, the current study provides evidence for the facilitative effect of acute exercise on the attentional and preparatory processes in a task that requires inhibition in children with ADHD. The results suggest that acute exercise leads to acceleration of response to Go stimulus in Go/No Go Task as well as exert its influence on the resource allocation of preparation as reflected by the CNV amplitudes. Although not directly measured, the modulation of arousal might be one of the mechanisms that mediates this effect. In addition, acute exercise may regulate the release of some particular neurotransmitters, such as DA, in children with ADHD. Such findings not only augment the evidence for the value of physical exercise but also indicate that behavioral preparation in the ADHD population can be improved by a single bout of exercise. The findings imply that this immediate effect of exercise may be applied to some specific occasions, such as break time between classes, for children with ADHD in order to improve their performance.

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