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The Selective Effect of Acute Aerobic Exercise on Neuroelectric Indices of Attention during Development

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Abstract

Background: A growing literature demonstrates the beneficial effects of aerobic exercise on higher-cognition during development. This study sought to investigate the specificity of the effects of acute aerobic exercise on attentional processing during development. This study also investigated whether maturation would interact with the effect of acute exercise on attentional processing.

Methods: Event-related potentials (ERPs) evoked by a 3-stimulus visual oddball task, were recorded in 8-9 (n=16) and 11-12 year-old (n=16) children. Two ERP components, each reflecting different attentional processes were studied (i.e., P3a and P3b). The P3b reflects attentional resource allocation during stimulus engagement, and the P3a reflects the orienting of focal attention to novel or distracting information. On separate days, and in a counter balance manner, the children completed the oddball task two times, once at following rest and once following 30 minutes of moderate aerobic (cycling) exercise.

Results: Relative to rest, the amplitude of the P3b was significantly greater following exercise for both age groups. No significant differences were observed for the amplitude or the latency of the P3a.

Conclusion: The present findings suggest that, regardless of age, acute aerobic exercise in children selectively benefits the neural resources underlying attentional resource allocation during stimulus engagement, with no influence on attentional orienting.

Keywords: Acute exercise; Development; Attention; ERPs; P3b; P3a

Introduction

With children becoming increasingly sedentary and opportunities for physical activity and exercise during the school day diminishing, understanding the benefits resulting from physical activity and exercise on cognition have never been more important. Meta-analyses reveal that acute aerobic exercise has a small but positive effect on cognitive functions in children [1], including decision making [2,3], cognitive control [4] and memory [5]. Moreover, there is evidence for a positive influence of acute aerobic exercise on spontaneous [6,7] and event-related brain activity [8]. Despite these robust findings, the specificity of the relation between acute aerobic exercise and attentional processing during development has yet to be examined.

One way to examine the specificity of the relation between acute aerobic exercise and attention is by evaluating event-related brain potentials (ERPs). ERPs reflect the synchronous activity of large populations of cortical neurons in the service of cognitive functions [9], and the high temporal sensitivity of this method enables researchers to parse the stimulus-response relationship into its constituent cognitive components. Accordingly, this method has been invaluable for articulating the neural underpinnings of exercise-induced changes in cognition [4].

One cognitive paradigm, the oddball paradigm, which requires participants to detect an infrequently occurring target stimulus amongst frequently occurring non-target/distractor stimuli, is of particular utility for examining attentional processes. These paradigms elicit two distinct but inter-related ERP components, the P3b and the P3a, which reflect differing attentional processes. Specifically, the P3b, evoked in response to an infrequently occurring target stimulus, is believed to reflect the allocation of attention during the revision of mental events [10,11]. As such, its amplitude is proportionate to the amount of resources allocated towards the suppression of extraneous neuronal activity in order to facilitate attention [11]. In contrast, the P3a, evoked in response to a distracter or novel stimulus, is believed to reflect attentional orienting to novel or distracting stimuli [11], such that increased amplitude relates to greater engagement of focal attention [11]. The latency of both sub-components is believed to reflect stimulus evaluation and classification speed, respectively [11].

Together, these components allow for a more precise understanding of attentional mechanisms than behavioral mechanisms alone. Furthermore, neuropharmalogical evidence suggests that these subcomponents relate to different neurotransmitter systems (P3b-Norepinephrine; P3a-Dopamine) [11,12]. Therefore, investigating how acute exercise differentially modulates these components may also provide valuable insight into the neurobiological mechanisms of exercise-induced changes in cognition. In fact, the only study to evaluate the P3b and P3a components following exercise, did so in adults and found a selective modulation for the P3b component [13]. As no prior paediatric investigation has examined both the P3b and P3a, the current study's primary aim is to examine the influence of acute aerobic exercise on multiple attentional processes by evaluating both P3 sub-components.

It has been suggested that the relation between acute aerobic exercise and cognition might be moderated by age [14]. Effectively, there might be more room for improvement in tests evaluating processes that are still undergoing maturation [P3b] compared to those that are relatively mature (P3a) [15,16]. However, few exercise studies systematically investigated different age groups of children [2,17], with results being equivocal, and no prior investigation evaluated the behavioral or neural correlates of attentional processes. Accordingly, the secondary aim of the current study is to assess whether acute aerobic exercise differentially influences attention in younger (8-9 year olds) and older (11-12 year olds) children. Given that in adults there is a selective modulation of the P3b component [13] and maturational differences between the P3b and P3a, we hypothesised that the increase in amplitude following exercise would be greater for the P3b than the P3a, and that this modulation would be greater in younger, relative to older children.

Materials and Methods

Participants

Participants were recruited from the Montreal area through the Université de Montréal recruitment services, and included thirty-two children equally divided into two age groups: 8-9 year-olds and 11-12 year-olds. All participants had normal or corrected to normal vision, and were free of neurological disorders, learning disabilities, and history of head injury, as verified by a health history and demographics questionnaire completed by guardian/s. Participant's demographic and fitness data are provided in (Table 1). Each participant's guardian read and signed an informed consent [approved by the Comité d'éthique de la recherche des sciences de la santé of the Université de Montréal], and each child provided verbal assent.

Variables	8-9 year-olds	11-12 year-olds
N	16 (7 males)	16 (7 males)
Age (years)	9.03 (0.43)	11.78 (0.56)
BMI (kg/m2)	15.92 (1.69)	18.45 (2.26)
Maximal aerobic power (W)	78.88 (14.09)	118.19 (22.86)
HRmax (bpm)	190.94 (10.25)	195.06 (6.8)
Mean exercise power (W)	38.62 (7.12)	57.94 (11.26)
Mean exercise HR (bpm)	148.12 (11.33)	149.44 (9.91)
Mean exercise OMNI-RPE	3.69 (2.30)	4.75 (1.92)
Note: BMI=Body Mass Index; HRmax=maximum heart rate achieved during maximal aerobic power test; mean exercise HR=mean heart rate during the cycling exercise at 50% of maximal aerobic power; mean exercise OMNI-RPE=average rating of perceived exertion during the cycling exercise at 50% of maximal aerobic power.		

Table 1: Participant demographic and fitness data.

Procedure

Each participant visited the laboratory on three separate days.

Day 1: During the first visit participants were familiarized with the laboratory, experimental equipment, and procedures. Following informed consent/assent, participants performed a test of maximal aerobic power [MAP] on a cycle ergometer. The first and second visit to the laboratory were always separated by a minimum of 48 hours to avoid any possible after-effect caused by the test of maximal aerobic power [MAP].

Days 2 & 3: During the second and third visit to the laboratory, participants were fitted with an EEG sensor net and completed a 3-stimuli visual oddball task. During one visit, the oddball task was completed after participants sitting on a bike, and during the other, following aerobic exercise (same bike). The order of intervention (rest versus exercise) was randomized, and half of the participants exercised on their second visit whilst the other half exercised during their third visit. During the rest day, participants came into the laboratory and sat on a cycle ergometer for thirty minutes. Participants were then fitted with an EEG sensor net, and completed the oddball task while seated in a chair in an electrically and sound shielded (faradized) room. During the exercise day, participants first completed the exercise protocol. Following exercise, participants were fitted with an EEG sensor and completed the oddball task in the same chair and room. EEG acquisition began approximately 10 minutes following exercise cessation, and the second and third visits were separated by a week. Each participant completed the oddball task at the same time of day, and half of the participants were tested in the morning whereas the other half was tested in the afternoon.

Fitness Assessment

MAP was determined by the McMaster protocol and was assessed for each participant to individualise the acute exercise session according to participant's own level of fitness. This test is specially designed for pediatric populations such that the initial load and the increments vary with sex and height [18]. The test was performed on cycle ergometer [Lode BV, Groningen, Netherlands] and stage duration was two minutes. During cycling, heart rate (HR) was continuously monitored (Polar Electro Oy, Finland), and ratings of perceived exertion (RPE) were assessed every two minutes using the

OMNI scale for cycle ergometer testing [19]. MAP was determined when the participant was no longer able to maintain a pedaling rate of 55 rpm. MAP and maximal heart rate (HRmax) data are provided in (Table 1).

Sub Maximal Exercise

The exercise session consisted of 30 minutes of cycle ergometry. The exercise intervention consisted of a five minute warm-up at 25% MAP, followed by 22 minutes at 50% MAP, and ended with a 3 minutes cool-down at 25% MAP. Participants were encouraged to maintain a target-pedaling rate of 55-65 rpm during the exercise session. During cycling, HR was continuously monitored and perceived exertion was assessed every two min using the OMNI scale. Table 1 provides HR and RPE data.

Cognitive Task

The 3-stimuli visual oddball task consisted of white rectangles [2.5 cm wide; 8.5 cm length] on a black background [20]. The standard stimulus was vertical (.75 probability], the target was slightly tilted from vertical [.125 probability], and the salient non-target was horizontal [.125 probability]. To ensure the same degree of task difficulty across the two age groups, the degree of tilt was determined in a pilot study [different group of children]. For the younger group, the target was tilted 3° from vertical, whereas for the older group it was tilted 2.5° from vertical. All stimuli were presented focally for 70ms, and the inter-stimulus interval ranged from 1600 to 2000 ms.

Participants sat 1 meter away from computer screen [distance from eye to screen] and were instructed to respond as quickly and accurately as possible with the index finger of their dominant hand when the target stimulus appeared. Participants completed 30 practice trials followed by 3 test blocks of 169 trials. Rest periods of 2 min were provided between each block. Total task time including rest periods was approximately 20 minutes.

EEG/ERPs

All EEGs were recorded using a 128-site Geodesic Sensor Net [EGI, Eugene, OR, USA]. Site impedance was kept below 50 kΩ, which is an acceptable level for high input impedance amplifiers [21], and each site was referenced to site Cz. Sensors placed above and below, and on the outer canthus of each eye, recorded electro-occulographic (EOG) activity. The EEG signal was amplified with Net Amps 200 amplifier (EGI, Eugene, OR, USA) and a band-pass filter was set at 0.1-100 Hz. The signal was digitalized at 250 Hz and the data were recorded with Net Station software [EGI, Eugene, OR, USA].

Offline data reduction was performed with Brain Vision Analyzer version 1.05 [Brain Products GmbH, Munich, Germany]. High and low pass filters were set at 0.1 and 30 Hz (24 dB/octave), respectively. Eye movements were corrected with the Gratton and Coles algorithm [22], and data were re-referenced to average mastoids. EEGs were segmented into 1400 ms epochs, consisting of a 200 ms pre-stimulus baseline and continuing for 1200 ms after stimulus onset. EEG artifacts were semi-automatically inspected and segments containing EEG activity exceeding ± 100 µV were rejected. Before averaging, trials for which participants gave an incorrect response, or with a reaction time exceeding ± 2.5 SD were rejected. P3a and P3b components were detected and defined as the maximum positive deflection occurring within a 300-500 and a 400-700 ms time window, respectively.

Statistical Analyses

All statistical analyses were performed with SPSS 16.0. Separate analyses were conducted on response accuracy for each stimulus category and on target stimulus reaction time. A series of 2×2 repeated measures ANOVAs were conducted with age group as the between group factor [8-9 and 11-12 year-olds] and condition as the within group factor [baseline and exercise] on behavioral variables for each condition of the task. For ERPs, separate analyses were conducted on the mean amplitude and the latency for each of the two components [i.e., P3a and P3b] and submitted to similar repeated measures ANOVAs as described above with the addition of the site [Fz, Cz, Pz] factor. Within subject effects are reported according to Greenhouse-Geisser's correction. For post-hoc analyses, confidence intervals were adjusted for multiple comparisons with Bonferroni's correction. An alpha level of .05 was used for all statistical tests.

Results

Behavioral performance

Statistical analyses of response accuracy for standard, target, and non-target did not reveal any effect of age (all $Fs \leq 0.01$, ns), indicating that task difficulty was similar across age. There was no effect of condition on response accuracy or reaction time (all $Fs<1.00$, ns) suggesting that behavioral performance on the oddball task was not affected by exercise. However, the analyses of reaction time did reveal a main effect of age (F [1,30]=5.35, $p<.05$, $\eta 2=.15$) with the 11-12 year-olds being faster (M=624.17, SD=75.79) than the 8-9 year-olds (M=693.34, SD=92.50), $t(30)=2.31$, $p<.05$, $d=.82$.

ERPs

P3b mean amplitude: The Analyses failed to reveal any significant interactions (all $Fs \leq 1.00$, ns); however, there was a main effect of condition (F [1,30]=4.99, $p<.05$, $\eta 2=.14$) and a main effect of site (F [1.57,47.19]=112.05, $p<.001$, $\eta 2=.79$). A pairwise comparison on the main effect of condition indicated that the mean amplitude of the P3b was greater following the exercise session (M=6.12, SD=1.18) compared to the baseline condition (M=3.98, SD=1.16) for sites Fz, Cz and Pz (Figure 1), t (30)=2.23, $p<.05$, $d=.33$. Pairwise comparisons for the main effect of site revealed that mean amplitude was significantly different for each site ($ts \geq 3.50$, $ps<.01$) with Pz>Cz>Fz.

P3b latency: There was no interaction or main effect of condition on P3b latency; however, the analyses showed a main effect of age group (F [1,30]=7.34, $p=.01$, $\eta 2=.20$), with a shorter latency for the older group (M=547.83, SD=47.61) compared with the younger group (M=616.96, SD=90.31), t (30)=2.71, $p=.01$, $d=.96$ (Figure 1).

P3a mean amplitude: The statistical analyses did not reveal any interaction or main effect of condition or age. There was a main effect of site (F [1.66,49.68]=, $p<.001$, $\eta 2=.67$). Pairwise comparisons indicated that mean amplitude was significantly different for each site (all $ts \geq 5.72$, $ps<.001$) with Pz>Cz>Fz (Figure 2).

P3a latency: There was no interaction or main effect of condition or age group. However, there was a main effect of sites (F [1.49, 44.66]=11.21, $p<.001$, $\eta 2=.27$). Pairwise comparisons indicated that latency at Pz was significantly shorter than at Cz (t [30]=3.74, $p<.01$, $d=.66$) and Fz (t [30]=3.51, $p<.01$, $d=.69$] (Figure 2).

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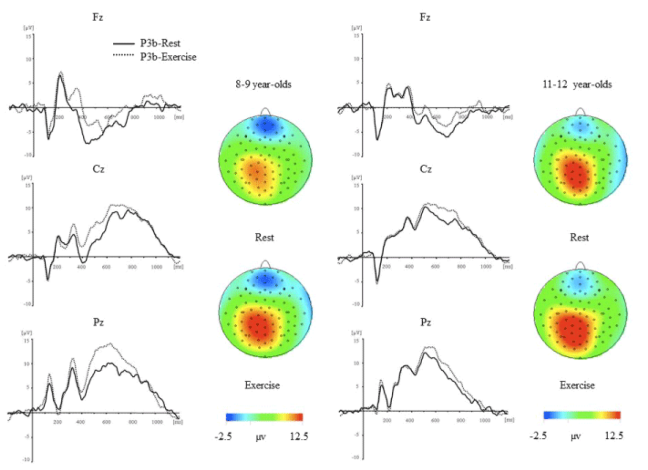

Figure 1: Grand average ERP waveforms and topographic plots elicited by target stimuli (P3b) for 8-9 and 11-12 year-olds at midline.

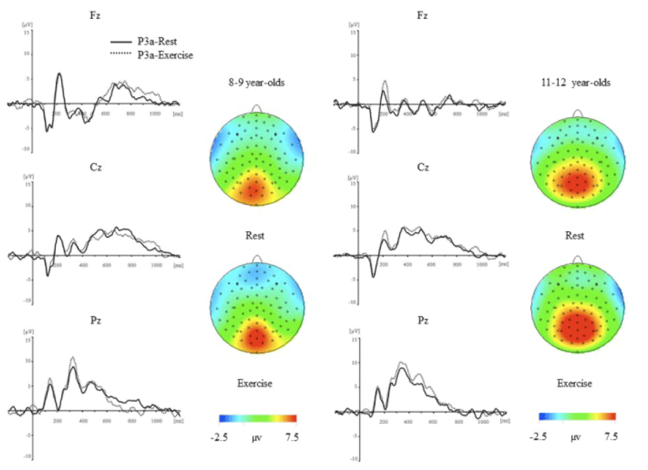

Figure 2: Grand average ERP waveforms and topographic plots elicited by non-target stimuli (P3a) for 8-9 and 11-12 year-olds at midline.

Discussion

The primary aim of this study was to investigate the specificity of 30 minutes of aerobic exercise on attentional processing in children. We also sought to examine the moderating effects of maturation. To do so 8-9 and 11-12 year old children completed an oddball task under two experimental conditions, following rest and following an acute bout of aerobic exercise. The results indicated that the P3b amplitude was greater following exercise relative to rest. However, no change was observed for the latency of the P3b or the amplitude/latency of the P3a. Moreover, the effect of exercise did not interact with the participant's age, indicating that irrespective of age, acute aerobic exercise appears to selectively influence the allocation of attention during target detection, but not attentional orienting.

Behavioral Performance

No effect of age was observed for response accuracy, indicating that task difficulty was similar for both the 8-9 and 11-12 year-olds. Further, we did not observe an effect of exercise on response accuracy, indicating that exercise did not alter the participants' ability to visually discriminate between target and non-target stimuli. This finding is not unexpected, however, as previous pediatric and adult studies demonstrate selective effects only for behavioral tasks requiring greater amounts of controlled processing [4]. As such, the current task may not have been challenging enough to elicit differences in response accuracy.

The results from the present study did replicate the common finding that reaction time improves with age [23,24], as the 11-12 year-olds were approximately 100 ms faster than the 8-9 year-olds. However, the results did not reveal any effect of acute aerobic-exercise on reaction time. This is consistent with findings from previous studies assessing the effect of acute aerobic exercise on ERP paradigms in children [8], adolescents [25] and adults [26], which suggest that moderate aerobic exercise may not influence response speed.

ERPs

In contrast to behavior, the evaluation of neuroelectric indices did reveal an effect of exercise. However, the effect was circumscribed to augmenting P3b amplitude, without any effect on P3b latency and P3a amplitude or latency. This selective modulation of P3b amplitude suggests that relative to rest, acute aerobic exercise selectively augments the magnitude attentional resource allocation during stimulus engagement [P3b amplitude], but not attentional orienting [P3a amplitude], or stimulus evaluation and classification speed [P3b/a latency]. In the only prior study evaluating the P3b and P3a following exercise [in adults, using a similar oddball paradigm], Pontifex and colleagues [In Press] also observed selectivity for P3b amplitude. The authors concluded that acute exercise-induced changes in cognition do not originate from overall modulation of attentional processes, but from specific aspects of attention. The current results reaffirm and extend this observation/assertion by demonstrating that acute aerobic exercise also selectively facilitates attentional resource allocation [P3b amplitude] during childhood.

Another goal of the present study was to assess whether age moderated the relation between acute exercise and cognition. First, clear age-related differences were observed for P3b latency between the two age groups with shorter latency for the oldest group, indicating the sensitivity of our task to developmental processes. This finding is consistent with the literature on the development of the P3b [15,16,27]. Despite a clear age effect for P3b latency, age did not interact with the effect of acute exercise. To date, results regarding the moderating effect of age/development on exercise-induced cognitive alterations are equivocal. One study reported greater cognitive benefits for 4th grade students when compared with 2nd and 3rd graders [17], whereas two other studies did not find any difference between 7 and 10 year-olds [2] or 7-8 and 9-11 year-olds [28]. With regards to attention, the current findings do not support the assertion that development moderates the influence of acute aerobic exercise on cognition. However, further research evaluating children, adolescents, and adults is necessary to further delineate the age-related trajectory of exercise-induced changes in P3b amplitude.

Mechanisms

The current results may be indicative of neurobiological selectivity, as accumulating evidence indicate that the P3b and P3a relate to different neurotransmitter systems [11,12]. The P3b is believed to be associated with noradrenergic firing emanating from the locus coeruleus and the integrity of the temporal–parietal junction [11,12,29,30], whereas P3a is generated by the dopaminergic firing in the frontal lobe [11,29]. Catecholamines are believed to play an important role in the effect of acute exercise on cognition [31,32], and evidence from animals [33] suggest that aerobic exercise may protect against depletion of norepinephrine in the locus-coreuleus, hippocampus, and amygdala. Accordingly, moderate intensity aerobic exercise may selectively optimize the bioavailability and firing of norepinephrine, resulting in the modulation of P3b amplitude. Although speculative, this theoretically-driven supposition should, at minimum, provide an impetus for research examining how neurobiological mechanism that give rise to exercise-induced changes in brain and cognitive functions.

Perspectives

The current results demonstrate that irrespective of age, acute aerobic exercise selectively influences attentional processes during development. Further, given our result's convergence with those observed in young adults [13], this selective modulation of attention might be present across the lifespan. Thus, the current study helps elucidate the nature of exercise-induced modulations in brain and cognitive function during development, and reinforces the assertion that exercise induced changes in cognition are not derivative of a general priming of attentional mechanisms [13]. Although meritorious, the current study is not without limitations. Although we used ERPs to assess levels of attention, oddball tasks enable only rudimentary assessment of attention on the behavioral level, and no exercise-related differences in behavior were observed. Further, the limited number of age groups (i.e., 9-10 year-olds and 11-12 year-olds) may have precluded our ability to detect an interaction with maturation. However, this is unlikely given the age-related differences in reaction time and latency and the similar selectivity observed in young adults. Irrespective of limitations, the current study provides valuable information regarding the benefits of acute aerobic exercise on brain and cognitive function, and reinforces the importance of physical activity during development.

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