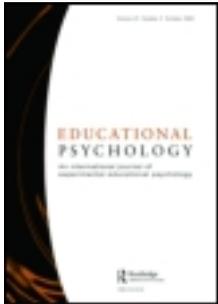


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Acute aerobic exercise impacts selective attention: an exceptional boost in lower-income children

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Educational research suggests that lower-income children exhibit poor general executive functioning relative to their higher-income peers. Meanwhile, sports psychology research suggests that an acute bout of aerobic exercise improves executive functioning in children. Yet, it has never been determined if such exercise (1) specifically improves the selective attention aspect of executive functioning in children or (2) impacts lower-income children any differently than higher-income children. The current study utilised a randomised experimental design and found that a 12 min session of aerobic exercise improved the selective attention of both lower- and higher-income children. Moreover, lower-income children exhibited even greater improvement than higher-income children. As the income-achievement gap persists, it is important to explore feasible interventions that strengthen the cognitive processes that underlie academic performance.

Keywords: aerobic exercise; executive function; selective attention; socio-economic

Executive functioning (EF) encompasses a variety of separable, but related cognitive processes required for the conscious control of thought and action (Latzman, Elkovitch, Young, & Clark, 2010; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Recently, a relationship between children's general EF and socio-economic status (SES) has been documented (see Hackman, Farah, & Meany (2010) for a brief review). For example, Lipina, Martelli, Vuelta, and Colombo (2005) found that young children from families of higher SES were, on average, more advanced in EF than children from families of lower SES. Similarly, when kindergarteners were given a battery of cognitive tests, higher-SES children outperformed lower-SES children on all tests and the most pronounced differences were on EF and language measures (Farah et al., 2006; Noble, Norman, & Farah, 2005). Socio-economic status has also been shown to account for a statistically significant amount of variance on EF tasks given to first graders (Noble, McCandliss, & Farah, 2007). Taken together, these findings suggest that lower-SES children tend to have poorer general EF skills than higher-SES children.

Importantly, general EF skills have also been shown to be related to academic achievement. A direct association between EF and children's early and developing mathematical skills has been found across a wide age range (e.g. Bull, Johnston,

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& Roy, 1999; Bull & Scerif, 2001; Espy et al., 2004; Gathercole, Pickering, Knight, & Stegman, 2004; McLean & Hitch, 1999; Passolunghi & Siegel, 2001). Executive functioning has been also been found to be related to achievement in reading (Helland & Asbjørnsen, 2000; Swanson, 1999) and reasoning (van der Sluis, de Jong, & van der Leij, 2007).

Like general EF ability, the specific attentional aspects of EF have been shown to vary across SES. Mezzacappa (2004) found associations between infants' SES and their performance on a measure of attentional processes when they were six years old. Similarly, Howse, Lange, Farran, and Boyles (2003) found lower-SES children did not regulate their attention to tasks as well as their higher-SES peers. Moreover, in the lower-SES group, the attention regulation scores predicted achievement test scores (Howse et al., 2003). Most recently, Stevens, Lauinger and Neville (2009) found that 3–8-year-olds from lower-SES families had lower selective attention scores than their higher-SES peers and used different neural processes when selectively attending to information. The growing documentation of income-related differences on EF attention tasks serves as an impetus to create interventions that target these skills in lower-income students, especially because performance on these tasks has been shown to be highly related to academic success.

Selective attention seems to be one particularly important attentional aspect of EF for academic success. Selective attention is defined as a performance-oriented, continuous and focused selection of stimuli. Central to this process is the capacity to selectively orient to certain relevant aspects of a task, while screening out irrelevant ones, and to analyse these dimensions rapidly and correctly (Brickenkamp & Zillmer, 1998). It has been suggested that it is used when learning to read (Stevens et al., 2009) and when solving math problems (Kercood & Grskovic, 2009). More generally, it is used when a student needs to follow directions or remain focused on one of many classroom activities occurring at any given time. In fact, a study of 3–5-years-old lower-income children found it to be an important correlate of math and reading ability independent of general intelligence (Blair & Razza, 2007). Furthermore, Waber, Gerber, Tucious, Wagner, and Forbes (2006) administered an EF battery that included selective attention tasks to lower-income fifth graders and found it accounted for 40% of the variance on their English standardised test scores and 30% of the variance on their mathematics standardised test scores (Waber et al. 2006, p. 459). In turn, the current study aims to test a school-based intervention to improve the selective attention abilities of lower- and higher-income children.

There is considerable empirical support for the finding that acute aerobic exercise benefits many aspects of children's EF, but the specific benefits to selective attention have not been tested. Acute aerobic exercise is achieved when a person engages in a brief single session of exercise at 70–80% of their maximum heart rate (American Heart Association, 2009). Ellemborg and St-Louis-Deschenes (2010) found that 7- and 10-year-old boys improved on a simple reaction and choice response time task after 30 min of aerobic exercise. Likewise, 7-, 8- and 9-year-olds that participated in 15 min of aerobic walking and stretching performed better on the Woodcock-Johnson Test of Concentration than those in a control group (Caterino & Polak, 1999). Hillman et al. (2009) found similar results with children of this age, indicating specifically that 20 min of aerobic exercise improves accuracy on an inhibition task. Notably, this study also showed that corresponding neuro-electric changes supported the behavioural improvements. Children's event-related potentials (ERPs) show that exercise caused a significant P300 amplitude increase,

indicative of enhanced concentration. These ERP changes were also shown to be associated with improved performance on an academic achievement test (Hillman et al., 2009). Stroth et al. (2009) found no improvement on teenagers' EF after 20 min of aerobic bicycling, but the authors admit that the non-statistically significant result may have been due to a ceiling effect on the modified EF task used. Collectively, the aforementioned studies provide convincing evidence that an acute bout of aerobic exercise can positively impact children's performance on a variety of EF tasks. It is now important to document how exercise specifically benefits children's selective attention. Moreover, it is important to understand how an easy-to-implement and low-cost intervention such as an acute bout of aerobic exercise may specifically affect the selective attention of children from lower-income areas, as extant studies have been conducted exclusively on middle- to higher-income samples.

Why would we expect lower-income children to be impacted any differently than those from more financially privileged backgrounds? As stated earlier, general EF skills have been shown to be disproportionately worse in children from deprived economic circumstances (Lipina et al., 2005; Mezzacappa, 2004; Noble et al., 2005, 2007). Therefore, it seems possible that lower-income children could improve more if they have more room to improve. Alternatively, there is evidence to suggest that there are shared physiological mechanisms impacted by poverty and exercise. The chronic stress associated with living in poverty increases baseline levels of cortisol (Chen, Cohen, & Miller, 2010; Cohen, Doyle, & Baum, 2006; Evans & English, 2002; Kunz-Ebrecht, Kirschbaum, & Steptoe, 2004; Miller, Chen, & Zhou, 2007). An acute bout of aerobic exercise also increases levels of cortisol, as well as brain-derived neurotrophic factor (BDNF) (Ferris, Williams, & Shen, 2007; Griffin et al., 2011; Viru & Viru, 2004). Importantly, these mechanisms are associated with cognitive performance (Ferris et al., 2007; Griffin et al., 2011; McEwen & Sapolsky, 1995). Theoretically, it is possible that the response to exercise may be different for lower- and higher-income children, as the physiological mechanisms that the exercise affects may have been impacted by poverty for lower- but not higher-income children. Measuring physiological responses is beyond the scope of the current study. Rather, the current study focuses on the important first step of documenting whether an acute bout of exercise does indeed impact the performance of lower- and higher-income children on selective attention tasks.

Specifically, the first goal of the current study is to determine if an acute bout of exercise impacts the selective attention aspect of executive functioning in children. While there is an established body of research documenting that acute bouts of exercise impact a variety of cognitive processes, its specific impact on selective attention in children has not yet been studied. Based on the literature showing exercise-related improvement on other EF tasks, it is hypothesised that an acute bout of aerobic exercise will also improve participants' performance on a selective attention task.

The second goal is to determine if an acute bout of aerobic exercise impacts the selective attention abilities of lower-income children any differently than higher-income children. Based on the literature showing income-related EF and physiological differences, it is hypothesised that exercise may have a different impact on the selective attention of lower- and higher-income students, although the hypotheses regarding the nature of such differences remain open.

A randomised experimental design was utilised to determine the degree to which an acute bout of aerobic exercise increases the selective attention of lower- and

higher-income middle school students. The current study is aligned with international efforts to address depressed school performance of lower-income students by exploring a reasonable, efficient and low-cost intervention.

Method

Participants

Participants ($n=164$) were sixth and seventh grade students at a public middle school in New England (age range: 10 years, 4 months–13 years, 6 months). Stratified sampling was used to randomly assign students to the experimental (exercise) or control (movie) condition. Participants in the experimental condition ($n=86$; 45 female and 41 male) included 44 lower-income participants and 42 higher-income participants. The control condition ($n=78$; 40 female and 38 male) was comprised of 36 lower-income participants and 42 higher-income participants. Participants were considered lower-income if the parent reported that the child qualified for a free lunch at school on a confidential information sheet sent home with the parental consent form. In the USA, children living in a household of four with an annual family income of less than \$29,055 qualify for a free lunch as part of the National School Lunch programme (United States Department of Agriculture, 2011). Participants were considered higher-income if the parent reported that the child did not qualify for a free *or* reduced lunch at school, meaning that they lived in a household equivalent to a family of four with an annual income of more than \$41,348. Participants that received a reduced priced lunch ($n=4$) were excluded from analyses and are not included in the sample sizes listed above. It is worth noting that the income criteria used in the current study are considerably more stringent than those used by many education and psychology studies. First, individual level income data were gathered, as opposed to relying on more general school or neighbourhood level classifications of SES. Second, the groups are specifically discussed as higher- and lower-*income* and not as high- and low-SES, as the data collected were related to income, but not maternal education or employment. Third, the lower-income participant pool was limited to only those students who receive free (as opposed to free and reduced) lunch while the higher-income participant pool was limited to those that were not eligible for either.

Procedure

Data collection occurred in two sessions held on two separate days during students' normally scheduled middle school gym classes. The first session was identical for both conditions. During the first session, each participant wore an Impact Sports ePulse Strapless Heart Rate Monitor. Participants were asked to sit still and breathe slowly for five minutes. After 5 min, the resting heart rate of each participant was recorded. Height and weight were measured. Age was reported. Researchers used height, weight and age to calculate each student's maximum heart rate, target heart rate and body mass index. See Measures section for formulas.

During the second session, the procedures differed for the experimental group and the control group. The experimental group was administered a paper and pencil version of the d2 Test of Attention (d2 pre-test) (Brickenkamp & Zillmer, 1998). The d2 Test of Attention measures selective attention by determining an individual's capacity to focus on one stimulus while suppressing awareness to competing

distracters (Brickenkamp & Zillmer, 1998). Next, each participant was fitted with an Impact Sports ePulse Strapless Heart Rate Monitor. Researchers informed each participant of their personal target heart rate range, which had been calculated based on the previously collected height, weight and age data. Then, participants ran around an indoor track for 12 min at a speed that maintained a heart rate within their target range. Researchers visually examined participants' heart rate monitors approximately every minute to ensure that participants remained within their target heart rate range. Participants whose heart rate went above or below their target heart rate range during the 12 min were excluded from analyses ($n=2$). One minute after the 12 min of exercise, the experimental group completed the d2 Test of Attention once again (d2 post-test).

The control group was administered the d2 pre-test, then remained seated and viewed a 12 min film clip about exercise produced by the Standard Deviants Academic Team (Cerebellum Corporation, 2004). One minute after the 12 min film clip, the participants completed the d2 post-test. The film was selected for a few specific reasons. First, it is an award winning educational video intended for middle school aged students. Second, the general content covered is about exercise, which is the same general content experienced by those in the experimental group. Presenting both conditions exercise-related content was done in an effort to control for the possibility that simply thinking about exercise may impact one's cognitive abilities. Lastly, watching short film clips is a common middle school classroom experience and was intended to mimic a sedentary activity children may engage in during a typical school day.

Measures

Physical characteristics

Body mass index (BMI). BMI was calculated by entering the height, weight and age of each participant into the Centre for Disease Control and Prevention's child BMI calculator (CDC, 2012). The height (inches) and weight of each participant was measured by a member of the research team. The age (months) of each participant was self-reported.

Resting heart rate. Resting heart rate was measured with an Impact Sports ePulse Strapless Heart Rate Monitor after participants sat still, in a cross-legged position, with their eyes closed and were asked to breathe slowly for 5 min.

Maximum heart rate. Maximum heart rate was calculated with the following formula: Heart rate (HR) max = $208 - (.7 \times \text{age})$, as suggested by Tanaka Monahan and Seals (2001).

Target heart rate range. According to the American Heart Association (2009), exercise is defined as aerobic when a person falls between 70 and 80% of their maximum heart rate (American Heart Association, 2009). Therefore, the target heart rate range for each participant was calculated using the following formula: $(\text{HR max} \times .7) - (\text{HR max} \times .8)$.

d2 Test of attention. The d2 Test of Attention was used to measure one's selective attention, the ability to focus on important stimuli while suppressing awareness of competing distractions. It is a one-page paper and pencil cancellation task of 14 rows (trials), each with 47 interspersed 'p' and 'd' characters (Brickenkamp & Zillmer, 1998). The characters have one to four dashes that are configured individually or in pairs above and/or below each letter. The target character is a 'd' with two

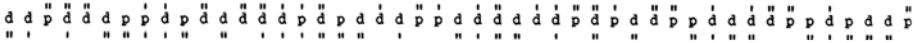


Figure 1. Sample d2 task trial.

dashes (hence ‘d2’), regardless of whether the dashes appear both above the ‘d’, both below the ‘d’ or one above and one below the ‘d’. Thus, a ‘p’ with one or two dashes and a ‘d’ with more or less than two dashes are distracter symbols. The participant’s task is to cross out as many target characters as possible, moving from left to right, with a time limit of 20 s per trial. No pauses are allowed between trials. See Figure 1 for a sample trial. The internal test–retest reliability of the d2 test has been shown to be very high for all parameters (0.95–0.98) and the criterion, construct and predictive validity have been documented and shown to be strong and stable (Brickenkamp & Zillmer, 1998). In 2004, Bates and Lemay sought to replicate the authors’ original reliability and validity reports because the d2 Test of Attention is such a well-used neuropsychological tool in Europe. They found it to be an internally consistent and valid measure with coefficients nearly identical to those previously reported. The measure was scored using the procedures outlined in the manual (Brickenkamp & Zillmer, 1998) which are described below:

Errors

Errors of omission (EO). The total number of d2 target symbols that were processed, but not crossed out across all 14 trials.

Errors of commission (EC). The total number of distracter symbols characters that processed and crossed out across all 14 trials.

Total number of errors (TE). The sum of EO and EC.

Selective attention

Processing speed/Total number of items processed (TN). The last (either correctly or incorrectly) crossed out letter in each row was considered the last item processed in that trial. TN was the sum of the total number of characters processed across all 14 trials.

Total number of correctly processed items (TC). $TN - TE$.

Design and analytic methods

The study employed a 2 (time: pre-test and post-test) \times 2 (condition: experimental [exercise] and control [movie]) \times 2 (income: higher and lower) mixed experimental design. In order to assess the effectiveness of the experiment on selective attention scores, a set of mixed design ANOVAs was run, as presented below.

Results

Physical characteristics

The resting heart rate, BMI, age and grade level distributions were compared across income levels and experimental groups. Results of independent sample t-tests showed no statistically significant differences between age, resting heart rate and

Table 1. Participant characteristics across condition and income level.

	Experimental (exercise) condition		Control (movie) condition	
	Lower-income <i>M</i> (SD)	Higher-income <i>M</i> (SD)	Lower-income <i>M</i> (SD)	Higher-income <i>M</i> (SD)
Resting heart rate	77.91 (1.21)	77.68 (1.27)	79.92 (1.34)	78.57 (1.24)
BMI	18.84 (.40)	18.97 (.42)	18.99 (.45)	19.14 (.41)
Age in months	148.09 (1.38)	145.35 (1.45)	147.81 (1.53)	148.26 (1.42)
Per cent (%) 6th grade	47.7	52.5	47.2	47.6

BMI between income levels or experimental groups (Table 1). Findings from chi-square analyses showed no statistically significant differences in the grade distributions across income levels or experimental groups.

d2 Test of attention

Selective attention

A $2 \times 2 \times 2$ mixed-design ANOVA with time as a within-subject variable, condition and income as between-subject variables, and selective attention scores (TC) as the dependent variable, revealed statistically significant main effects of time ($F(1, 158) = 281.78, p < .001, \eta_p^2 = .64$) and condition ($F(1, 158) = 27.793, p < .001, \eta_p^2 = .15$). The main effect of time showed that across condition and income, students had higher selective attention scores on the post-test than on the pre-test. The main effect of condition indicated that across time and income, students in the exercise condition had higher selective attention scores than students in the movie condition.

There were also statistically significant two-way interactions between time and condition ($F(1, 158) = 222.849, p < .001, \eta_p^2 = .585$) and time and income ($F(1, 158) = 11.66, p < .001, \eta_p^2 = .069$). Simple effects tests for the interaction between time and condition indicated that regardless of income, selective attention scores of students in the experimental group improved from pre-test to post-test ($F(1, 158) = 523.24, p < .001, \eta_p^2 = .768$), whereas the scores of the students in the control group did not statistically significantly improve ($F(1, 158) = 1.66, p > .05$). Simple effects tests for the interaction between time and income indicated that though both lower- and higher-income students improved in selective attention from pre-test to post-test, lower-income students showed more improvement, based on effect sizes, ($F(1, 158) = 200.60, p < .001, \eta_p^2 = .559$) than higher-income students ($F(1, 158) = 90.96, p < .001, \eta_p^2 = .365$), regardless of condition. As the next set of results clarifies, this result was due to the improvement seen in the experimental group, as there were negligible pre-test–post-test differences for both income groups in the control group.

Most notably, a significant three-way interaction among time, condition and income qualified the results reported above ($F(1, 158) = 6.75, p < .05, \eta_p^2 = .041$). This interaction indicates that condition impacted selective attention scores for higher- and lower-income students differently (Figure 2).

Bonferroni-corrected simple effects tests revealed that the control condition did not statistically significantly impact the selective attention scores of lower-income or higher-income participants. Meanwhile, in the experimental condition, both the

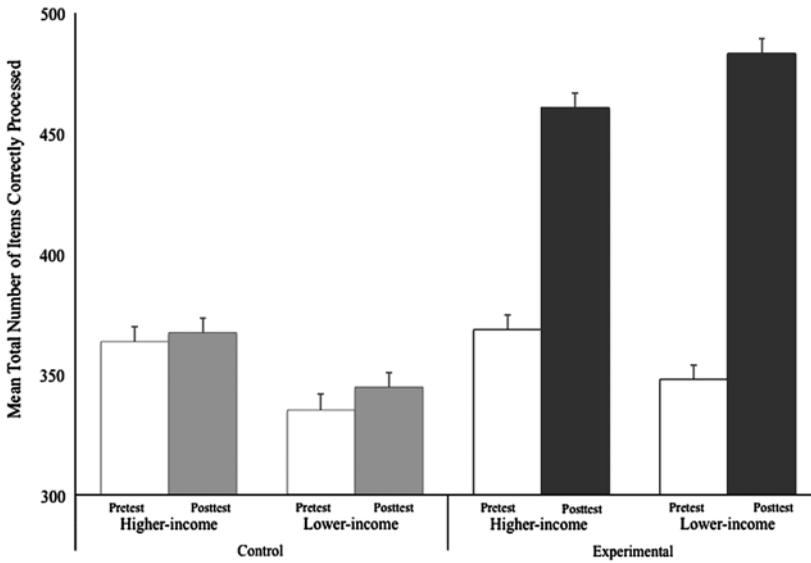


Figure 2. The effect of condition on selective attention in higher- and lower-income students.

lower-income and higher-income participants improved, $F(1, 158)=388.73$, $p<.001$, $\eta_p^2=.71$ and $F(1, 158)=164.02$, $p<.01$, $\eta_p^2=.51$, respectively. A comparison of the magnitude of effect sizes of pre-test to post-test differences suggests that the lower-income participants showed more improvement than higher-income participants, driving the significant three-way interaction.

To test this difference directly, change scores were calculated for each participant by subtracting their pre-test TC from their post-test TC. A 2 (income level: higher and lower) \times 2 (condition: control and experimental) ANOVA was run on the entire sample with change score as the dependent variable. The main effects of income ($F(1, 158)=10.53$, $p<.01$, $\eta_p^2=.06$) and condition ($F(1, 158)=218.46$, $p<.001$, $\eta_p^2=.58$) were both significant, but can be best understood in the context of the significant income by condition interaction. Bonferroni corrected simple effects tests revealed that there was no difference in the change score of higher- vs. lower-income students in the control condition. However, there was a significant difference in the change score of higher- vs. lower-income students in the experimental condition, $F(1, 158)=18.87$, $p<.001$, $\eta_p^2=.11$), with the lower-income students ($M=135.23$, $SE=6.85$) having a greater change score than the higher-income students ($M=92.13$, $SE=7.18$).

Participants were also stratified into low or high baseline selective attention groups based on their performance on the d2 pre-test. Those that scored above the median were categorised into the high baseline selective attention group and those that fell below the median into the low baseline selective attention group. Chi-square analyses run on the full sample and within each condition showed no significant differences in the distribution of income level across high and low selective attention baseline groups. Similarly, independent sample t-tests run on the full sample and within each condition showed no difference between income groups on the selective attention pre-test. However, to investigate if the exercise condition

impacted those with low baseline selective attention more than those with high baseline selective attention, regardless of income, a 2 (baseline selective attention: high and low) \times 2 (condition: control and experiment) ANOVA was run on the participants with change score as the dependent variable. There was a significant main effect of condition ($F(1, 158)=209.90, p<.001, \eta_p^2=.57$) suggesting across baseline selective attention groups, students in the experimental condition had a larger change score than those in the control condition, $M=114.70, SE=3.88$ and $M=7.78, SE=3.61$, respectively. There was also a significant main effect of baseline attention score ($F(1,158)=8.67, p<.01, \eta_p^2=.05$), indicating that, across condition, those with low baseline selective attention increased more than those with high baseline selective attention $M=75.80, SE=5.68$ and $M=51.25, SE=5.42$, respectively. However, the interaction of baseline attention score and condition was not significant, $p>.05$.

Errors

The types of errors made by participants were also analysed. A mixed-design ANOVA was run with condition (experimental and control) and income (lower and higher) as between subject variables and time (pre-test and post-test) and error type (omission and commission) as within subject variables. The dependent variable was the proportion of errors. These were calculated for each error type on both the pre-test and post-test by dividing TE by TN. For omission errors, the proportion of omission errors made on the pre-test and post-test was computed by dividing the EO made on each test by the TN. The same computations were made for commission errors on the pre-test and post-test. No statistically significant main effects or interactions were found.

Discussion

This study investigated if an acute bout of aerobic exercise could improve the selective attention aspect of executive functioning in higher- and lower-income middle school students. Participants took a selective attention task before and after either watching a 12 min video (control group) or engaging in 12 min of aerobic exercise (experimental group). As expected, watching a 12 min video did not impact the selective attention performance of either the higher- or lower-income students. However, 12 min of aerobic exercise did statistically significantly improve the selective attention performance of both higher- and lower-income students. Specifically, students processed a larger number of items correctly, while not increasing the proportion of errors made. This finding fits with an established body of research suggesting that acute bouts of aerobic exercise can improve EF skills (see Best, 2010; McMorris & Graydon, 2000; Tomporowski, 2003). Moreover, it extends the literature by being the first study to our knowledge showing that acute bouts of aerobic exercise specifically benefit selective attention in children. This addresses the call in Best's (2010) review that the field better clarifies the specific EF components impacted by acute aerobic exercise.

The second important finding was that lower-income students demonstrated significantly greater improvement on the d2 test than the higher-income students as a result of the acute bout of aerobic exercise. It is important to highlight that the current study defined participants as higher- or lower-income in a dichotomous manner,

based on if they lived in a house with a family household income of above \$41,348 or below \$29,055, respectively. Using this stratification method did not allow us to disentangle the unique contributions of factors such as ethnicity, community poverty, chronic stress or more discrete levels of income. Nonetheless, the patterns found in the current study provide an important initial understanding of the ways in which acute bouts of exercise differentially impact children of lower- and higher-income.

The finding that lower-income children saw such large improvements in their selective attention skills poses acute bouts of exercise as a promising intervention for schools serving lower-income communities. Why should these schools focus on boosting the selective attention abilities of their students? As stated earlier, selective attention is frequently used in classroom contexts and has been found to be predictive of math and reading ability (see Blair & Razza, 2007; Kercood & Grskovic, 2009; Stevens et al., 2009; Waber et al., 2006). In addition, the specific selective attention measure used in the current study has been shown to be associated with various measures of more general cognitive ability. When middle school teachers were asked to identify the 20% of students they thought exhibited the highest and lowest drive, those categorised as being highly driven had significantly better d2 scores than those with categorised as having low drive (Brickenkamp & Zillmer, 1998). In a sample of more than 500 college students, significant correlations were found between d2 performance and the Halstead-Reitan Neuropsychological Test Battery, Stroop Colour Word Test, Wechsler Adult Intelligence Scale Information and Picture Completion subtests (Davis & Zillmer, 1998). All of these results suggest that the d2 task taps an important and well-used cognitive skill. In turn, our finding that a mere 12 min of aerobic exercise can dramatically improve the selective attention of lower-income students is highly encouraging, as selective attention is associated with academic and cognitive outcomes.

It was surprising to find no income differences on the selective attention pre-test. Based on the body of literature reporting that lower-income children lag behind their higher-income peers on a variety of academic and cognitive measures, it was hypothesised that lower-income children would perform less well than the higher-income children on the pre-test. Indeed, Stevens and colleagues (2009) found income differences in selective attention, although they measured selective auditory attention as opposed to selective visual selective attention and worked with younger children. Interestingly, like the current study, Lupien, King, Meaney, and McEwen (2001) found no behavioural selective attention differences between higher- and lower-income 10–12-year-old children, the age of the participants in the current study. They did, however, find income differences on selective attention tasks for both 6- and 16-year-olds, suggesting possible developmental differences in selective attention. Ardila and Rosselli (1994) suggest similar age-related developmental patterns of attention skills. Moving forward, it will be important to determine the impact of exercise on selective attention for lower- and higher-income students of all ages so that interventions can be appropriately targeted.

While lower-income children did not have lower baseline selective attention scores than higher-income children, the results did show that the participants with low baseline skills improved more than those with high baseline skills, regardless of experimental condition. Other literature has also found that people with low baseline EF skills (e.g. working memory) benefit the most from interventions (see Sibley & Beilock, 2007). This pattern may explain why the low baseline children in the experimental condition saw more improvement than the high baseline

children. As for those that improved in the control condition, perhaps the low baseline students were more susceptible to practice effects.

Moving forward, this line of work has educational implications. In fact, the methodological design of the study was specifically planned so that school personnel could easily replicate the exercise session in schools. First, the exercise session was quick enough to be realistically embedded within a typical school day. Previous studies that have investigated ways in which aerobic exercise benefits children's cognition have implemented exercise bouts that last between 20 and 30 min (see Best (2010) for a review), approximately twice as long as the 12 min used in the current study. To our knowledge, only two other studies investigate benefits following less than 20 min of aerobic exercise (see Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Caterino & Polak, 1999). It is promising that such short periods of acute aerobic exercise can benefit cognition, as it makes it a reasonable intervention for schools constrained by tight schedules. Second, the only equipment needed that schools may not already have in inventory is a set of reasonably priced heart rate monitors.

An acute bout of aerobic exercise could be implemented during various parts of a school day. For example, physical education (PE) classes could intentionally be scheduled before academic classes. PE classes could also be required to include acute aerobic activity, thereby allowing students to reap cognitive benefits as well as intended physical benefits. Unfortunately, instead of capitalising on PE, there is a current decrease in the number of schools even offering PE. Further, these PE classes are being cut most often from schools in lower-income communities, which serve the students that, based on our results, seem to reap the most cognitive benefit (National Association for Sport and Physical Education, 2010). Recess is another opportunity for schools to implement acute aerobic exercise, but the amount of school time dedicated to recess has also declined (Storey, Kaphingst, & French, 2006). Acute bouts of aerobic exercise could also be integrated into regular classroom time, as well. For example, students could engage in brief sessions of aerobic activity before standardised tests to ensure they are operating at peak performance.

Future work should address how long the selective attention benefits from an acute bout of exercise last for higher- and lower-income children. Other findings suggest that the EF benefits seen from exercise last more than a few minutes, underscoring the potential utility of quick exercise sessions during the school day. Specifically, three studies have found an improvement on EF tasks that began 2–3 min after an exercise session, but lasted 10–20 min (Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; Lichtman & Poser, 1983; Sibley, Etnier, & Le Masurier, 2006). Two other studies evaluated executive functioning 30 min after an exercise session and found improvement (Hillman, Snook, & Jerome, 2003; Tomporowski et al., 2005). However, some cognitive benefits seen during exercise, such as performance on a random number generation task, fade as soon as the exercise is terminated (Audiffren, Tomporowski, & Zagrodnik, 2009). Thus, it will be important to determine how long the impact of exercise benefits the selective attention skills of higher- and lower-income children.

In a time when the income-achievement gap is large and pervasive, it is critical to identify potential interventions that are low in cost and easy for schools to implement. The current study suggests that providing students opportunities to participate in acute bouts of aerobic exercise may be a propitious strategy for improving selective attention. Moreover, lower-income students seem to benefit the most.

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