The effect of acute physical exercise on cognitive function during development

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ABSTRACT

Although accumulating research suggests that acute physical exercise ameliorates cognitive function in adults, little is known about the effects of acute exercise on cognition during development. We assessed simple reaction and choice response times in 7- and 10-year-old boys (n = 36 per age group). Half of the children completed 30 min of aerobic exercise, whilst the other half watched television. Each child was tested immediately prior to and immediately following the intervention. Compared to the control group, the children in the exercise condition showed a significant improvement on both tasks, with a better outcome for the choice compared to the simple task. These findings indicate that physical exercise also has an impact on cognitive functioning in children.

Accumulating research with human adults suggests that a single session of physical exercise ameliorates different aspects of cognitive function immediately after the end of the exercise period, regardless of fitness level (Brisswalter, Collardeau, & Arcelin, 2002; Etnier et al., 1997; Tomporowski, 2003). However, until recently the relationship between acute physical exercise and cognitive function was not so obvious because the literature on the topic seemed to provide somewhat contradictory findings. Indeed, whilst a certain number of studies indicated that short periods of physical exercise improved cognitive functioning in adults (Hancock & McNaughton, 1986) others either did not find any benefits (Bard & Fleury, 1978; Cote, Salmela, & Paphthanasopoulou, 1992; Fleury, Bard, Jobin, & Carriere, 1981) or even reported deterioration of cognitive function (Cian, Barraud, Melin, & Raphel, 2001; Isaacs & Pohlman, 1991; Wisberg & Herbert, 1976).

It has now been more clearly demonstrated that the effect of physical exercise on cognitive performance depends both on the intensity and the duration of the exercise (Etnier et al., 1997; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Tomporowski, 2003). First, intense but brief exercise does not appear to have much of an effect on brain function (Hancock & McNaughton, 1986; Tzorbatzoudis, Barkoukis, Danis, & Gouios, 1998). For example, no change in perception, sensory integration, or visual discrimination is noted immediately after voluntary physical exhaustion (i.e., approximately 10 min of cycling or running at about 150% of VO\(_{2\max}\)) (Bard & Fleury, 1978; Fleury et al., 1981). In contrast, prolonged but sub-maximal physical exercise leading to dehydration is associated with a reduction in cognitive performance. For example, a 2 h run on a treadmill at 65% of VO\(_{2\max}\) results in a significant disruption of short-term memory, psycho-motor abilities, and visual discrimination (Cian et al., 2001). Finally, physical exercise of moderate intensity and duration appears to ameliorate brain function. In fact, several studies found that immediately after an exercise session of sub-maximal intensity (i.e., heart rate of about 110–130 beats per minute) and a duration of 20–40 min, there is an improvement in sensori-motor and cognitive performance (Clarkson-Smith & Hartley, 1989; Hogervorst, Riedel, Jeukendrup, & Jolles, 1996). Although much of the evidence suggests that the relationship between acute physical activity and cognitive performance has an inverted U function, it is important to interpret these findings with some caution given that the paradigms of the studies cited above differ along several important domains, such as the type of aerobic exercise, the cognitive functions assessed, the age groups tested, as well as the physical and health condition of the participants.

Much of the literature that reports beneficial effects of exercise use reaction time tasks (Etnier et al., 1997; Tomporowski, 2003). Reaction time is the response time from the appearance of a stimulus to the motor response and it is believed to reflect stimulus identification, response selection, and response programming. It is also considered as a general indicator of functional integrity of the central nervous system (Wang, 2008). The typical explanation for the facilitating effect of acute exercise on reaction time is an increase in physiological arousal induced by the exercise (Brisswalter et al., 2002; Gutin, 1973; Kamijo et al., 2004; McMorris & Graydon, 1997). However, the even greater facilitating effects of exercise on choice
response time (also tapping cognitive processes including executive functions) compared to simple reaction time (mainly tapping a sensory motor response), suggests an increase in cognitive arousal induced by exercise (Clarkson-Smith & Hartley, 1989).

Although accumulating research suggests that an acute bout of physical exercise of moderate intensity and duration ameliorates cognitive function in adults, much less is known about the effects of a single session of physical exercise on cognitive functioning during development. Only a handful of studies investigated the effects of acute physical exercise on cognitive functioning during development (Caterino & Polak, 1999; Gabbard & Barton, 1979; Hillman et al., 2009; McNaughton & Gabbard, 1993; Raviv & Low, 1990; Zervas, Danis, & Klissouras, 1991). However, these studies report disparate findings. For example, whilst one study found improved cognitive functioning after 15 min of aerobic exercise and stretching (Caterino & Polak, 1999), another study only noted an enhancement of cognitive function after 50 min of exercise (i.e., systematic relays during physical education class) (Gabbard & Barton, 1979). In addition to the disparate findings it is difficult to draw conclusions from the results of these studies either because academic skills rather than specific cognitive functions were tested (e.g., arithmetic computation) (Gabbard & Barton, 1979; McNaughton & Gabbard, 1993), little to no details about the physical activity were provided (such as intensity and heart rate) (Caterino & Polak, 1999; Gabbard & Barton, 1979; Raviv & Low, 1990), the control condition consisted in participating in a regular academic activity (Caterino & Polak, 1999; Raviv & Low, 1990), or the data were pooled over a wide range of ages (e.g., 11–14 years of age) (Zervas et al., 1991).

The purpose of the present study was to determine whether short periods of physical exercise ameliorate cognitive function in children and whether this effect varies with age during development. To do so, we assessed sensori-motor and cognitive functions, using a simple reaction time task and choice response time task, respectively, in groups of 7- and 10-year-old boys (n = 36 children per age group). Half of the children in each age group completed an aerobic activity of sub-maximal intensity (approximately 130 beats per minute, or 60% of maximum heart rate) for a duration of 30 min, whilst the other half watched a television show of the same duration. Each child was tested twice, immediately before and after the intervention.

Methods

Participants

Seventy-two boys, unaware of the experimental objectives, participated in this study; half of the children were 7 years of age and the other half were 10 years of age. Only boys were included because of known gender differences on attentional mechanisms (Adam, Robert, Rory, & Mark, 2001). For each of the two age groups, 18 children participated in the control condition and 18 participated in the experimental condition. No participant data were discarded; all participants who accepted to participate in the study completed the experimental procedure and the tests. By means of developmental questionnaires completed by the parents we selected children without academic difficulties, learning disabilities, attention deficit disorders, known medical conditions, neurological and developmental disorders. All were born at term and had normal birth-weights. A series of t-tests indicated that there are no significant differences between the control and experimental groups with regards to mean height, weight, and number of hours per week spent participating in various types physical activities (including organized and individual sports as well as leisure activities) (see Table 1 for participant details).

Procedures

The children were randomly assigned to be part of the experimental and the control groups. All testing was done individually in the laboratory setting. Specifically, both the control and the experimental conditions took place in a same temperature regulated room, testing was always done in the afternoon, and the children were permitted to drink water at all times, save during the reaction time tasks. The children in the experimental group cycled for about 30 min (plus a 5 min warm-up and a 5 min cool-down) on an ergometer (Ergomeca model GP440) whilst watching a popular children’s show that was age appropriate. The children included in the control group sat still on the same ergometer for a period of 40 min whilst watching the same television show. Both groups completed the same simple reaction and choice response time tasks immediately before and after the intervention.

The height of the seat was adjusted for each child. Heart rate was taken as a measure of the intensity of performance, and it was monitored using telemetry (Polar protrainer™). For the experimental condition, the first 5 min consisted of a warm-up period during which heart rate was raised to reach a target level of about 130 beats per minutes. This was done by adjusting resistance. The children then peddled for 30 min at a rate that allowed them to maintain their target heart rate of 130 beats per minute. The experimenter recorded heart rate every 2 min, and when necessary, instructed the child to increase or decrease peddling speed in order to maintain target heart rate. This allowed us to reach mean values of 134 and 132 beats per minute during the 30 min cycling period for the 7- and 10-year-olds, respectively. This corresponds to 63% of maximum heart rate for each group (Ricart-Arguirre, Léger, & Massicotte, 1990). The 30 min cycling period was followed by a cool-down that lasted until the children’s heart rate returned to about 100 beats per minute (±5 beats per minute).

Experimental measures

We created the following simple reaction and choice response time tasks using Matlab™ (The MathWorks Inc.). The simple reaction time task taps low level sensori-motor functions associated with primary visual and motor cortices. This paradigm consisted of geometric forms (square, triangle, and circle) presented in four different colours (red, black, blue, and yellow) that appeared on a computer monitor for a duration of 700 ms each. At a viewing distance of 57 cm, each form sub-tended about 4° of visual angle. Inter-stimulus interval varied randomly from 500 to 4000 ms. The participant’s task was to press a key as soon as he detected the form on the screen. Each of the 12 stimuli (3 forms × 4 colours) was presented 10 times for a total of 120 presentations. This task lasted about 5 min. The dependent variable is the time required to respond.

The choice response time task is a cognitive task involving decision making processes that tap certain aspects of executive functions in the frontal lobe such as flexibility and inhibition (Stuss et al., 2005). The stimuli and presentation parameters are the same as in the previous task. However, in this task the participant is

| Table 1 | Participant details. |
|---|---|---|---|
| | 7-year-olds | 10-year-olds |
| Control | Experimental | Control | Experimental |
| Mean age (yrs) | 7.8 | 7.6 | 10.5 | 10.6 |
| Mean height (cm) | 126 (7) | 122 (7) | 141 (9) | 137 (8) |
| Mean weight (kg) | 24.4 (52) | 26.2 (5.6) | 34.3 (7.5) | 32.7 (8.1) |
| Mean physical activity per week (h) | 7.4 (3.7) | 6.5 (3.1) | 8.9 (3.4) | 8.1 (4.2) |
asked to press a key each time a circle appeared on the screen and a different key for any other form. Therefore, of the 12 stimuli, four were targets and the rest were distractors. Each of the 12 stimuli was presented 20 times for a total of 216 presentations. This task lasted about 10 min. The two dependent variables that are analysed are response time for correctly identified targets and response accuracy (i.e., hits/total number of targets).

To familiarise the children with the tasks and to obtain a baseline measure of performance, each child completed the simple and choice tasks before the experimental procedure (watching television versus watching television whilst cycling). The children were then retested a second time after the intervention. In all groups and for both the baseline and post-intervention measures, the simple reaction time task always preceded the choice response time task. These measures were obtained in a quiet testing room whilst the children were comfortably seated in a regular chair. The children responded by pressing a key with the index of their dominant hand.

Statistical analyses

The simple and choice reaction time data were analysed separately by means of a 3-way analysis of variance (ANOVA) with a between-subjects factors of age (7-year-olds versus 10-year-olds), a between-subjects factor of condition (control condition versus experimental condition), and a within subject factor of time of test (baseline test versus post-intervention test). Significant interactions were further analysed with Tukey post-hoc tests.

Results

Fig. 1 presents the data for the simple reaction time task for the experimental and the control groups. The ordinate shows the mean response time in milliseconds. The ANOVA for the simple reaction time task revealed a significant interaction of time of test × condition $F(1,68) = 10.26, p < .002$. Main effects of age $F(1,68) = 172.61, p < .001$, condition $F(1,68) = 5.49, p < .02$, and time of test $F(1,68) = 41.75, p < .001$ were also revealed. There were no significant interactions of age × condition, age × time of test, nor of age × condition × time of test (all $ps > .10$). The analysis of the interaction between time of test (before versus after intervention) and condition (television only versus exercise and television) indicates that for both age groups, the children in the exercise condition were significantly faster on the choice response time tasks than the children in the control group. Together, these results suggest that the activity benefited both age groups equally.

Fig. 2 presents the data for the choice response time task for the experimental and the control groups. The ANOVA for the choice response time task revealed significant interactions of time of test × condition $F(1,68) = 45.63, p < .001$, and of time of test × age $F(1,68) = 12.26, p < .001$. Main effects of age $F(1,68) = 601.05, p < .001$, condition $F(1,68) = 38.80, p < .001$, and of time of test $F(1,68) = 179.93, p < .001$ were also revealed. There were no significant interactions of age × condition nor of age × condition × time of test (all $ps > .10$). The analysis of the interaction between time of test (before versus after intervention) and condition (television only versus exercise and television) indicates that for both age groups, the children in the exercise condition were significantly faster on the choice response time tasks than the children in the control group. Again, these results suggest that the activity benefited both age groups equally.

Discussion

We investigated the effects of an acute bout of physical activity on cognitive functioning during development. The results indicate that a single and short session of aerobic activity of moderate intensity significantly improves response time for the simple and choice tasks.

Although factors like physical fitness or academic achievement were not measured, they are unlikely to explain the differences reported between the children who were active and those who were inactive. To participate in the study all children had to meet the same inclusion criteria (viz., age appropriate level of academic achievement, no academic difficulties or learning disabilities, and no neurological or other medical conditions). Further, the children were randomly assigned to be part of either one of the two conditions. The statistical analyses indicate that the baseline measure of the two groups did not significantly differ. It is also unlikely that the control condition (i.e., watching television) had a negative influence on the results by inducing fatigue or decreasing vigilance and attention. First, the children in the exercise group also watched television, as did the children in the control group. Further, and most notably, the children who only watched television also showed a slight
The findings from the present study indicate that a single session of exercise has a positive impact on the simple reaction time task and on the choice response time task. Compared to the control group, the children who participated in the aerobic exercise responded on average 34 ms faster on the simple reaction time task and 75 ms faster on the choice response time task after the intervention. Because the enhancement in response speed was 2.2 times greater for the choice response time task compared to the simple reaction time task, these results suggest that exercise also ameliorates cognitive functioning and not only sensory and motor responses. This is supported by recent studies conducted to isolate the locus of exercise-induced facilitation on simple reaction time that indicate a selective influence of acute aerobic exercise on motor response (Audiffren, Tomporowski, & Zagrodnik, 2008; Davranche, Burle, Audiffren, & Hasbroucq, 2005, 2006).

Despite the improvement in response time for the choice task, accuracy remains unchanged and is similar for the control and the experimental groups. This finding has two implications. First, the fact that accuracy was not deteriorated in the experimental group indicates that the improvement in response time measured for this group was not at the detriment of accuracy. On the other hand, the fact that only response time and not response accuracy improved suggests that the latter is not a sensitive measure of cognitive change related to physical exercise.

The present results do not support the hypothesis that the beneficial effects of physical activity on cognitive performance vary with age. These results are inconsistent with those of Caterino and Polak (1999) that suggest a relationship between age and the beneficial effects of acute physical activity on cognitive functioning. Specifically, these authors found an amelioration in selective visual attention in a group of fourth-grade children but not in second- and third-grade children following 15 min of aerobic exercise. Several important differences between studies, such as the parameters of the physical exercise (intensity and duration), the cognitive functions tested, and subject characteristics could possibly account for the disparate findings. Further, it is possible that the particular test used in that study and the fact that it was administered collectively was not particularly favourable for the two younger age groups tested.

As noted in the Introduction, recent reviews of the literature indicate that in adults the effect of physical exercise on cognitive performance depends both on the intensity and the duration of the exercise (Brisswalter et al., 2002; Kamijo et al., 2004; Tomporowski, 2003). Specifically, beneficial effects on cognitive functioning are reported for an exercise session producing a sub-maximal aerobic intensity (i.e., 20–80% of maximum heart rate) that is maintained for 20–40 min. The results from the present study indicate that children also experience cognitive improvement when intensity and duration parameters fall within that range. However, we still do not know if the upper and lower limits of the intensity and duration parameters are the same for children as they are for adults. To our knowledge, one study investigated the effect of exercise duration whilst none measured the effect of intensity. Gabbard and Barton (1979) found an improvement on a test of mathematical skills only after 50 min of activity and not after 20, 30, or 40 min. Differences in exercise intensity and cognitive tasks could possibly explain why we found benefits after 30 min of activity whilst they did not.

The influence of physical exercise on the brain’s neurochemistry and oxygen concentration has often been proposed to explain the amelioration in sensory and cognitive performance associated with acute bouts of physical activity. For example, augmentation in serotonin concentrations associated with exercise (Vaynman & Gomez-Pinilla, 2005) is consistent with findings from studies of human electroencephalography that show an increase in beta power immediately after a session of aerobic exercise (Oda, Matsumoto, Nakagawa, & Moriya, 1999; Youngstedt, Dishman, Cureton, & Peacock, 1993). Energy in the beta frequency band reflects cortical activation related to information processing and top-down attention processing.

In conclusion, the results from the present study suggest that exercise has a beneficial impact on different aspects of brain functioning during development. Indeed, both sensori-motor and cognitive functions are ameliorated. However, the present work does not allow us to determine the duration of the reported effects; further research is needed to elucidate this question. Additional work is also required to verify for possible gender differences given that only boys were tested in the present study.

References


