Physical activity and cognition in children

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Effects of a physical activity intervention during recess on children’s physical fitness and executive functioning

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Abstract

The objective of this study was to analyze the effects of a physical activity program including both aerobic exercise and cognitively engaging physical activities on children's physical fitness and executive functions. Children from three primary schools (aged 8-12 years) were recruited. A quasi-experimental design was used. Children in the intervention group (n = 53; 19 boys, 34 girls) participated in a 22 week physical activity program for 30 minutes during lunch recess, twice a week. Children in the control group (n = 52; 32 boys, 20 girls) followed their normal lunch routine. Aerobic fitness, speed and agility, and muscle strength were assessed using the Eurofit test battery. Executive functions were assessed using tasks measuring inhibition (Stroop test), working memory (Visual Memory Span test, Digit Span test), cognitive flexibility (Trailmaking test), and planning (Tower of London). Children in the intervention group showed significantly greater improvement than children in the control group on the Stroop test and Digit Span test, reflecting enhanced inhibition and verbal working memory skills respectively. No differences were found on any of the physical fitness variables. A physical activity program including aerobic exercise and cognitively engaging physical activities can enhance aspects of executive functioning in primary school children.
5.1 Introduction

Research indicates that development of children’s executive functions might benefit from increased physical activity (Barenberg, Berse, & Dutke, 2011; Best, 2010). However, the specific characteristics of exercise that will be most beneficial for children’s executive functions remains a topic of debate (Tomporowski, McCullick, Pendleton, & Pesce, 2015). Executive functions is an umbrella term that refers to the cognitive processes responsible for purposeful and goal-directed behavior (Banich, 2009), and include a wide range of abilities of which inhibition, working memory, cognitive flexibility, and planning are mentioned as core executive functions (Anderson, 2002; Miyake et al., 2000). Executive functions develop as a child’s brain matures, with accelerated development between 7 and 9 years of age, and have been positively linked to academic achievement (Van der Niet, Hartman, Smith, & Visscher, 2014). It is suggested that regular aerobic exercise at moderate to vigorous intensities can induce neurochemical and morphological changes in brain areas associated with executive functioning (Best, 2010). In addition, cognitive demands inherent in most physical activity and play during childhood might directly impact the development of executive functions (Best, 2010).

Results from meta-analytic studies in children show positive relations between physical activity and executive functions (Sibley & Etnier, 2003), as well as improved executive functioning with acute exercise (Verburgh, Königs, Scherder, & Oosterlaan, 2014). Studies on the effects of chronic exercise aiming to improve executive functions are scarce, and show mixed results. For example, Davis et al. (2011) found an increase in planning skills in overweight children following a 13 week aerobic exercise program after school. However, Fisher et al. (2011) failed to find positive effects of a 10 week increased physical education intervention on cognition. In addition, two studies found that a nine month physical activity program after school designed to improve cardiorespiratory fitness, led to improvements in working memory performance (Kamijo et al., 2011), as well as inhibition and cognitive flexibility (Hillman et al., 2014) in preadolescent children. Both studies showed that in addition to improvements on executive functions, children in the intervention group also demonstrated greater improvement on aerobic fitness compared to the control group, suggesting a mediating role of aerobic fitness. In a study by Crova et al. (2014), overweight children showed higher improvement in inhibitory ability than overweight controls and lean peers following a six month enhanced physical education program. Interestingly, their intervention consisted of object control skills in
tennis, which were assumed to be cognitively challenging. Aerobic fitness did not mediate the effects, suggesting that the cognitive challenges inherent in open skill tasks might have led to improved inhibitory ability.

It thus seems that additional aerobic training or cognitively engaging physical activity can lead to improvements on executive functioning in children. This suggests that including both aspects in a physical activity program will likely be most beneficial. Therefore, the current intervention focused on improving executive functioning by providing a physical activity program that included both aerobic exercise at moderate to vigorous intensities, and cognitively engaging physical activities. It was expected that including complex play settings like team games would create situations to effectively train executive functions (Best, 2010). The aim was to examine the effects of this program on the physical fitness of children (including aerobic fitness and strength components), and their performance on a broad range of executive functions. The physical activity program was run during lunch recess, facilitating implementation of the program within the time constraints of the school program. It was hypothesized that children in the intervention group would show greater improvements on physical fitness and executive functions after the intervention than their control peers who didn't participate in the program.

5.2 Methods

Participants
A total of 112 typically developing children (56 boys, 56 girls) aged 8-12 years participated in this study. Children were recruited from three primary schools in the northern part of The Netherlands. A quasi-experimental design was used; based on parental consent children were allocated to either the intervention or control group. Seven children were excluded from analysis as a result of missing data due to moving school during the intervention period. The final sample consisted of 105 children, of which 53 children (19 boys, 34 girls) participated in the intervention group (Table 5.1). Most children came from similar socioeconomic backgrounds: 82% of the children had an average socioeconomic status (SES) based on the education of the parents. The intervention and control group differed in gender ratio, with more girls in the intervention group, and more boys in the control group. There were no significant differences between both groups in terms of age, height, weight, BMI and the percentage of children with normal weight and overweight/
obese. Informed consent was obtained from the children’s parents/guardians prior to participation. All procedures were in accordance with and approved by the ethical committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Table 5.1. Descriptive statistics for children in the intervention and control group at baseline.

<table>
<thead>
<tr>
<th></th>
<th>Intervention group</th>
<th>Control group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>53</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>19</td>
<td>32</td>
<td>.01*</td>
</tr>
<tr>
<td>Girls</td>
<td>34</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Age (year)</td>
<td>8.8 (0.8)</td>
<td>8.9 (1.2)</td>
<td>.52c</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>141.5 (7.6)</td>
<td>142.5 (9.5)</td>
<td>.55c</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>35.0 (6.8)</td>
<td>33.9 (7.1)</td>
<td>.42c</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.4 (2.5)</td>
<td>16.6 (2.2)</td>
<td>.08c</td>
</tr>
<tr>
<td>% normal weighta</td>
<td>74</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>% overweight/obesea</td>
<td>26</td>
<td>15</td>
<td>.17b</td>
</tr>
</tbody>
</table>

**Note.** Values are expressed as means (SD). * Calculated from cut-off criteria of Cole, Bellizzi, Flegal, and Dietz (2000).  
b Non parametric Chi square test. c Student’s t-test.  
* p < .05

**Study design**

All children followed their normal daily school routine, including two physical education lessons per week. The intervention group received additional physical activity programmed on two non-physical education days. Children in the intervention group followed the physical activity program during lunch recess, and had their lunch at school. Children in the control group had lunch as they normally did, either at home or at school. Physical fitness and executive functions were assessed at baseline and posttest. All children were tested individually by trained examiners, who were unaware of the child’s experimental group. One week after the baseline tests, the physical activity intervention program started. Children needed to participate in 80% of the program to be included in the intervention group.

**Training program**

The intervention primarily focused on increasing physical activity during lunch time at school. The emphasis was on intensity and enjoyment, in order to make sure children would continue participation in the program. A 22 week, twice a week physical activity
program was designed. The intervention was run in the games room within the school, making it easy to implement. Activities were selected based on intensity, cognitive effort, and practical feasibility. The program consisted of activities at moderate to vigorous intensity, such as running games and circuit training, in which children were executing exercises like sit-ups, push-ups or rope skipping. In addition, activities requiring cognitive effort were included, such as tag games and modified football games, as well as relay games with letters that had to be spelled into a word. Each session lasted approximately 30 minutes and consisted of a warming up (5 minutes), a core activity (20 minutes), and a cooling down (5 minutes), in which both aerobic exercise and cognitively engaging activities were included. The intensity of the intervention was controlled by measuring heart rate of all participants during three randomly selected sessions, using a Team 2 Polar system (Polar Vantage). During core activities, mean heart rate was 149.2 (±15.5) bpm. Based on their maximum heart rate, this intensity ranged from 57 to 88 % of the maximum, which represents moderate to vigorous physical activity. The intervention was provided by student physical education teachers.

Measures of physical fitness
Physical fitness was assessed using four tests from the European physical fitness test battery (EUROFIT) (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988). The tests included were the standing broad jump (SBJ, in cm), sit-ups (SUP, number in 30 seconds), the 10x5 meter shuttle run (10x5m SR, in seconds) and the 20-meter shuttle run (20m SR, in stages). Explosive leg strength was measured with the SBJ. In this test, the child is asked to jump as far as possible with two feet from a standing position. In the SUP, children have to perform as many sit-ups in 30 s, as a measure of trunk strength and endurance. Running speed and agility were measured using the 10x5m SR, in which the child is asked to cover a distance of 50 meters in total by running 10 times 5 meters back and forth between two lines. The 20m SR test measures cardiovascular endurance. In this test children run back and forth between two lines 20m apart, pacing their run to audio signals that progressively increase in difficulty. The 20m SR test was measured during a normal physical education lesson, while the remaining three tests were completed in circuit form in a random order during another physical education lesson. The test-retest reliability, ranging from .62 to .97, and construct validity of the four tests for children are adequate (Léger, Mercier, Gadoury, & Lambert, 1988; Van Mechelen, Van Lier, Hlobil, Crolla, & Kemper, 1991).
Executive functions measures

Inhibition, which is the ability to control attention and behavior while suppressing distracting stimuli (Diamond, 2013), was tested with the Golden version of the Stroop test. In this test, the child has to complete three reading conditions in 45 seconds each, by reading out aloud words written in black ink (Word card), the colors of colored rectangles (Color card) or the color of the ink in which words are written (Color-Word card) (e.g. the word 'green' written in blue ink). In all three conditions, the number of correctly mentioned items is scored. Inhibition was measured by a ratio score ($I_R$), calculated by dividing the score obtained for the third card by the score for the second card; $I_R = CW/C$ for number of correctly items scored. This is a method to assess inhibition ability, independently of the child's ability to read or name colors (Lansbergen, Kenemans, & Van Engeland, 2007). A higher ratio score indicates better ability to inhibit distractions. The Golden version has been used in children from age 5. Test-retest reliability coefficients of the three separate cards are high ($r > .80$) (Strauss, Sherman, & Spreen, 2006).

Visuo-spatial working memory was assessed with the Visual Memory Span (VMS) test, and verbal working memory using the Digit Span (DS) test. Both tests are part of the Wechsler Memory Scale revised (Wechsler, 1987), and measure the ability to hold and manipulate information in mind (Diamond, 2013). In the VMS test a child has to replicate in reverse (backward) order a sequence of movements made by the examiner pointing in a predefined order at colored squares on a paper. The test starts with two sequences and increases to seven sequences, with two attempts at each level, resulting in a maximum of 12 attempts. The test discontinues when the child is unable to repeat two sequences of the same length. In the digit span (DS) test the child has to repeat in backward order a sequence of spoken digits that are read aloud by the examiner. The test starts with two sequences and increases to eight sequences, with three attempts at each level, resulting in a maximum of 21 attempts. The test is discontinued when the child is unable to repeat two attempts of the same length. In both tests, each correct trial is awarded with one point. The maximum score for the VMS test is 12 points, for the DS 21 points, with higher scores indicating better performance. VMS and DS tests have been used in children from age 6, and show reliability ranging from .70 to .90 (Strauss et al., 2006).

Cognitive flexibility was assessed using the Trailmaking test (TMT), a paper and pencil task in which children are asked to connect circles in numerical order (trail A), and alternating between both numerical and alphabetical order (trail B), by drawing a line from one point to the next as quickly as possible (Reitan, 1971). To obtain an accurate
measure of cognitive flexibility, which is the ability to shift attention between stimuli (Anderson, 2002), the time to complete trail A is subtracted from the time to complete trail B (Strauss et al., 2006). The TMT has been used and validated in children from age 7 (Strauss et al., 2006).

The Tower of London (ToL, Shallice, 1982) examines the ability to plan and sequence a behavior towards a goal. In this task a child has to move three colored balls between three pegs of differing heights in order to reproduce a depicted target pattern from a fixed start state, in a prescribed number of moves (Baker, Segalowitz, & Ferlisi, 2001). This implies that the child creates a strategy and keeps in mind the target pattern while evaluating their progress after each move. A total of 12 problems have to be solved that vary in difficulty according to the number of required moves, starting with two and increasing to five moves. The child has three attempts to solve each problem. Points are assigned when a child solves the problem, with a maximum of three points for each problem, resulting in a maximum score of 36. The ToL has been tested and validated for use with children from age 7 (Anderson, Anderson, & Lajoie, 1996).

**Statistical analysis**

Data analyses were performed using SPSS 20.0 for Windows (IBM Corp., Armonk, NY, USA). Analyses of covariance (ANCOVA) were used to test group differences on physical fitness and executive functioning measures at posttest, adjusting for gender and baseline scores. Covariates (age, SES) were included if they were related to the dependent variable. Level of significance was set at 5% (α = .05).

### 5.3 Results

Six children in the intervention group were excluded from analyses as they participated less than 80% of the sessions, bringing the total sample to 99 children. As the intervention group consisted of relatively more girls, it was decided to include gender as a covariate in all analyses. Age was related to SBJ (r = .31, p = .002), TMT (r = -.35, p < .001), and ToL (r = .25, p = .01) posttest score, and was included as covariate in all corresponding analyses. SES was not related to any of the dependent variables and was left out of the analyses.
Table 5.2. Unadjusted scores on physical fitness and executive functioning by group at baseline and posttest, and estimated means at posttest adjusted for baseline scores and covariates.

<table>
<thead>
<tr>
<th></th>
<th>Intervention group (n = 47)</th>
<th></th>
<th>Control group (n = 52)</th>
<th></th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Posttest</td>
<td>Adjusted post</td>
<td>Baseline</td>
<td>Posttest</td>
</tr>
<tr>
<td><strong>Physical fitness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBJ* (cm)</td>
<td>131.7 (2.8)</td>
<td>132.5 (3.2)</td>
<td>134.6 (2.2)</td>
<td>135.4 (2.9)</td>
<td>140.0 (3.3)</td>
</tr>
<tr>
<td>10x5m SR* (s)</td>
<td>23.0 (0.3)</td>
<td>22.9 (0.3)</td>
<td>22.9 (0.2)</td>
<td>23.2 (0.3)</td>
<td>22.7 (0.3)</td>
</tr>
<tr>
<td>SUP* (n)</td>
<td>14.6 (0.8)</td>
<td>16.6 (0.6)</td>
<td>17.1 (0.5)</td>
<td>15.4 (0.5)</td>
<td>17.2 (0.7)</td>
</tr>
<tr>
<td>20m SR* (stage)</td>
<td>3.8 (0.2)</td>
<td>4.2 (0.2)</td>
<td>4.5 (0.2)</td>
<td>4.2 (0.2)</td>
<td>4.5 (0.3)</td>
</tr>
<tr>
<td><strong>Executive functioning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop* (ratio)</td>
<td>.64 (0.02)</td>
<td>.68 (0.02)</td>
<td>.68 (0.02)</td>
<td>.68 (0.02)</td>
<td>.64 (0.01)</td>
</tr>
<tr>
<td>VMS* (points)</td>
<td>7.0 (0.2)</td>
<td>7.2 (0.2)</td>
<td>7.2 (0.2)</td>
<td>7.0 (0.2)</td>
<td>7.0 (0.2)</td>
</tr>
<tr>
<td>DS* (points)</td>
<td>6.1 (0.3)</td>
<td>7.2 (0.3)</td>
<td>7.2 (0.3)</td>
<td>6.1 (0.2)</td>
<td>6.4 (0.3)</td>
</tr>
<tr>
<td>TMT* (s)</td>
<td>79.7 (5.0)</td>
<td>65.1 (3.8)</td>
<td>63.7 (3.9)</td>
<td>77.9 (4.4)</td>
<td>69.5 (4.4)</td>
</tr>
<tr>
<td>ToL* (points)</td>
<td>27.5 (0.5)</td>
<td>29.3 (0.4)</td>
<td>29.4 (0.4)</td>
<td>27.8 (0.5)</td>
<td>29.9 (0.4)</td>
</tr>
</tbody>
</table>

Note. * A higher score indicates a better performance. † A lower score indicates a better performance. Values are expressed as means (SD) or estimated means (SE). Adjusted means at posttest adjusted for gender and baseline scores (all variables), and age (SBJ, TMT, ToL). SBJ = Standing broad jump. 10x5m SR = 10x5 meter shuttle run. SUP = Sit-ups. 20m SR = 20-meter shuttle run. Stroop = Stroop color word test. VMS = Visual memory span test. DS = Digit span test. TMT = Trailmaking test. ToL = Tower of London.

* p < .05
Table 5.2 shows the results of the ANCOVA for the physical fitness and executive functioning measures. Significant differences between the intervention and control group were found on adjusted posttest scores for the Stroop test (F(1, 97) = 3.07, p = .04, \( \eta^2_p = .03 \)) and Digit Span test (F(1, 96) = 4.50, p = .02, \( \eta^2_p = .05 \)), indicating that children in the intervention group showed greater improvement on inhibition and verbal working memory scores compared to children in the control group, when taking the test score at baseline into account. The accompanying effect sizes were small (Stevens, 1996). No significant differences between the intervention and control group were found on the other executive functioning measures, and any of the physical fitness variables. Interaction effects of group and gender or group and age were not significant for all physical fitness and executive functioning measures.

5.4 Discussion

This study tested the effects of a physical activity program during lunch recess, on physical fitness and executive functioning of primary school children. The intervention consisted of aerobic exercise and cognitively engaging activities. It was found that children in the intervention group showed a significantly greater improvement on the Stroop test, measuring inhibition, and on the DS test, which measures verbal working memory, in comparison to the control group. No significant effects were found on the other executive functioning measures and any of the physical fitness variables.

Physical fitness, including aerobic and strength components, did not significantly improve in the intervention group compared to the control group. This might be due to the frequency or intensity of the intervention. While the intensity of the physical activity intervention was found to be moderate to vigorous in three randomly selected sessions, this might not have been representative for all sessions. In addition, aerobic fitness of children has a strong genetic component, and might need more frequent or intense activity programs to differentiate from gains due to normal growth and development (Baquet, Van Praagh, & Berthoin, 2003). Nevertheless, as research on children's behavior during recess shows that they are active at low intensities, with only small amounts of time spent in moderate to vigorous physical activity (Ridgers, Stratton, & Fairclough, 2005), providing a physical activity program during recess can contribute to increase time spent in moderate to vigorous physical activity.
The improvements found on inhibition and working memory are broadly consistent with findings from Hillman et al. (2014) and Kamijo et al. (2011) who also found effects of an intervention on inhibition and working memory respectively. While it is frequently mentioned that inhibition is the first executive function to emerge during early childhood, it shows its greatest development during late childhood (6 to 10 years of age), with mastery of this skill evident around 12 (Jurado & Rosselli, 2007). Inhibition might therefore be most sensitive to environmental factors around ages 6-12 years. Improvements on the DS test reflect improvements in memory strategies, that may reflect a more effective working memory network (Kamijo et al., 2011). Working memory is shown to be related to inhibition (Davidson, Amso, Anderson, & Diamond, 2006). Perhaps the activities of the physical activity program required the children to hold information in working memory while inhibiting interfering information, leading to improvements in those domains. It is however notable that the Stroop test and the DS test are the most simple executive functioning tasks, without involving a visuomotor component. In a review on the effects of physical activity on executive functioning in children, the authors (Barenberg et al., 2011) conclude that the more difficult the executive functioning measure, the more difficult it was to find an effect.

Results of this study show improvements on aspects of executive functioning without an improvement in aerobic fitness, suggesting that the cognitively engaging physical activities may account for these improvements. It has been demonstrated that executive functions must continually be repeated and challenged by increases in task difficulty to promote improvements in children (Diamond, 2013). Children engaging in a lot of different activities involving both physical and cognitive effort, will therefore show gains in executive functioning, even in low dose physical activity, as has also been shown in a study by Crova et al. (2014). While this seems to contradict the aerobic exercise interventions used by Kamijo et al. (2011) and Davis et al. (2011), in both studies games and motor skills were included in the physical activity program in order to keep their participants motivated to continue. This suggests that also in these interventions cognitive engaging activities were included that might have had an effect on executive functioning. It thus seems to be difficult to clearly differentiate between aerobic exercise and cognitively engaging exercise. More research is needed to investigate this, and to determine children’s optimal challenge point in terms of intensity and cognitive engagement of physical activity.

The current study provides some insight into the effects of in school physical activity interventions on fitness and cognition in children, however there are some study
limitations. First of all, it was not possible to randomly assign children to the intervention and control group, which resulted in an unequal distribution of boys and girls in both groups. In addition, the control group followed their normal routine during lunch time, and there was no control on their physical activity behavior. Also, while this study used multiple measures for executive functioning, including more indices of each executive functioning would strengthen the results. Nevertheless, the findings from the current study provide evidence that executive functioning can be improved by providing extra physical activity at school.

5.5 Conclusion

This study shows that physical activity interventions within a school day are feasible without complex changes of time schedules. Offering a physical activity program twice a week during lunch recess was shown to be beneficial for inhibition and verbal working memory in children aged 8-12 years. Interventions focusing on aerobic fitness should also include cognitively engaging activities to enhance executive functioning in preadolescent children.
References


