Physical activity and cognition in children
van der Niet, Anneke Gerarda
Associations between daily physical activity and executive functioning in primary school-aged children

Anneke G. van der Niet\textsuperscript{a}, Joanne Smith\textsuperscript{a}, Erik J.A. Scherder\textsuperscript{a,b}, Jaap Oosterlaan\textsuperscript{b}, Esther Hartman\textsuperscript{a}, Chris Visscher\textsuperscript{a}

\textsuperscript{a} Center for Human Movement Sciences, University of Groningen, University Medical Center Groningen, The Netherlands

\textsuperscript{b} Department of Clinical Neuropsychology, VU University Amsterdam, The Netherlands

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Abstract

Objectives: While there is some evidence that aerobic fitness is positively associated with executive functioning in children, evidence for a relation between children's daily physical activity (PA) and their executive functioning is limited. The objective was to examine associations between objectively measured daily PA (total volume, sedentary behavior, moderate to vigorous physical activity (MVPA)) and executive functioning in children.

Design: Cross-sectional.

Methods: Eighty primary school children (36 boys, 44 girls) aged 8-12 years old participated in the study. Physical activity (PA) was measured using accelerometers. Executive functions measured included inhibition (Stroop test), working memory (Visual Memory Span test), cognitive flexibility (Trailmaking test), and planning (Tower of London: ToL). Total volume of PA, time spent in sedentary behavior and MVPA were calculated and related to performance on executive functioning.

Results: More time spent in sedentary behavior was related to worse inhibition ($r = -0.24$). A higher total volume of PA was associated with better planning ability, as reflected by both a higher score on the ToL ($r = 0.24$) and a shorter total execution time ($r = -0.29$). Also, a significant moderate correlation was found between time spent in MVPA and the total execution time of the ToL ($r = -0.29$).

Conclusion: Children should limit time spent in sedentary behavior, and increasing their total PA. Total volume of PA, which consisted mostly of light intensity PA, is related to executive functioning. This opens up new possibilities to explore both the quantity and quality of PA in relation to cognition in children.
3.1 Introduction

The relationship between exercise and cognition in children has been frequently studied. A meta-analytic review by Sibley and Etnier (2003) showed that physical activity (PA) was significantly related to improved cognition in school-aged children. Besides, some studies show that fitter children, with greater aerobic fitness based on directly measured oxygen consumption, perform better or more accurately on executive functioning tasks compared to their lower fit peers (Buck, Hillman, & Castelli, 2008; Pontifex et al., 2011). Executive functions encompass a subset of cognitive operations used to effortfully guide behavior towards a goal (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, and play an important role in the cognitive, behavioral, and social-emotional development of children (Anderson, 2002). It is suggested that development can be facilitated by activities that challenge executive functioning (Diamond & Lee, 2011). Regular involvement in PA in early childhood is thought to be one of the activities that can stimulate the development of executive functions (Best, 2010). PA is defined as all bodily movement produced by the muscular system that increases energy expenditure above normal physiological demands (Ortega, Ruiz, Castillo, & Sjöström, 2008), while sedentary behavior is marked by low energy expenditure.

There is some evidence from intervention studies showing that engaging in moderate to vigorous physical activity (MVPA) can lead to improvements in certain aspects of executive functioning in children (Davis et al., 2011; Fisher et al., 2011). However, in these studies children’s PA behavior is stimulated beyond their normal PA. It remains unclear if children’s habitual PA, which is the typical activity pattern of children in daily life including their sedentary behavior, is related to performance on executive functioning. PA and sedentary behavior might be independently related to executive functioning. Aerobic exercise can lead to both neurochemical and morphological changes in brain regions associated with executive functioning (Best, 2010). Additionally, the cognitive demands of children’s PA have the potential to influence executive functioning in several ways (Best, 2010). Group games can challenge inhibition skills and working memory, or require the child to shift attention or act according to a plan. In contrast, sedentary behavior would not be expected to stimulate executive functioning in these ways, and has been shown to be associated with EF problems (Riggs, Huh, Chou, Spruijt-Metz, & Pentz, 2012). We thus
believe that PA (even at low intensity) is inherently more demanding on EF than sedentary behavior.

In a systematic review by Keeley and Fox (2009), no studies were found that examined the links between daily PA and executive functioning in typically developing children. A study in boys with Attention Deficit Hyperactivity Disorder (ADHD) showed that the time spent in MVPA was a significant predictor of planning ability (Gapin & Etnier, 2010). A recent study on daily PA in adolescent males showed that higher MVPA was associated with better executive attention performance (Booth et al., 2013). However, total volume of PA, which mainly consisted of light PA, was a predictor of lower executive functioning performance. In both studies, the link between sedentary behavior and executive functioning was not examined. However, as research on PA of children in Europe showed high levels of sedentary behavior (Verloigne et al., 2012), studying this association is needed.

The purpose of this study therefore was to examine the relationships between objectively measured daily PA and core aspects of executive functioning in primary school children, i.e. their inhibition, working memory, cognitive flexibility, and planning skills. In particular, we studied how the total volume of PA, MVPA and sedentary behavior were related to executive functioning. It was hypothesized that the total volume of PA and MVPA would be positively associated with performance on executive functioning measures, and that sedentary behavior would be linked to poor performance on executive functioning measures.

### 3.2 Methods

A total of 80 typically developing children (36 boys, 44 girls) aged 8-12 years participated in this study. Children were recruited from three primary schools in the northern part of The Netherlands. Most children came from similar socioeconomic backgrounds: 82% of the children had an average socioeconomic status (SES) based on the education of the parents. No statistical differences were found between boys and girls with respect to chronological age, height or weight, as depicted in Table 3.1. Statistical differences were found between boys and girls on Body Mass Index (BMI) and the percentage of children with normal weight and overweight/obese ($p < .05$), with girls showing significantly higher BMI and a higher percentage in the category overweight/obese than boys (Table 3.1). In
all instances, 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 3.1. Descriptive statistics for the total sample and for boys and girls separately.

<table>
<thead>
<tr>
<th></th>
<th>All (n = 80)</th>
<th>Boys (n = 36)</th>
<th>Girls (n = 44)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Age (year)</td>
<td>8.9</td>
<td>1.0</td>
<td>8.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>142.6</td>
<td>9.3</td>
<td>142.9</td>
<td>7.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>36.0</td>
<td>9.2</td>
<td>34.0</td>
<td>6.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.5</td>
<td>2.8</td>
<td>16.6</td>
<td>2.3</td>
</tr>
<tr>
<td>% Normal Weighta</td>
<td>77</td>
<td></td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>% Overweight/Obeseb</td>
<td>23</td>
<td></td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

Note. a Calculated from cut-off criteria of Cole, Bellizzi, Flegal, and Dietz (2000). b Student's t-test. c Non-parametric Chi square test.

PA was measured with a hip mounted accelerometer (ActiGraph GT3x+, Pensacola, FL, USA), for seven consecutive days (Trost, Pate, Freedson, Sallis, & Taylor, 2000). This device measures acceleration in three directions and records with a frequency of 100 Hz. Children were asked to wear the accelerometer every day during waking hours, except during swimming or bathing, or in certain other cases when the accelerometer could be damaged (self-defensive or contact sports). Data were collected from October through February.

Data were analyzed using data analysis software ActiLife6 (ActiGraph, ActiLife version 6.7.1). A recording epoch of 10 s was used. Data recorded on the first afternoon were discarded in order to minimize any influence of changes in behavior as a result of wearing the device. All accelerometer data were visually reviewed to check the quality of the data. When data were below a valid activity floor of 10 counts/min for 20 consecutive minutes, data were flagged as non-wear period and excluded from analysis. Children had to provide a minimum of 3 weekdays and 1 weekend day of at least 9 hours of wear time each day. Data from only the vertical axis were used and evaluated for the volume of PA (mean counts/min), and time spent at different intensity levels, using the cut-off points of Pulsford et al. (2011): sedentary: <100 counts/min, corresponding to activities such as lying and sitting; moderate: >2240 and ≤3840 counts/min, reflecting brisk walking;
vigorous: $\geq 3841$ counts/min, which is best represented by an activity like jogging. Daily accumulation of MVPA was assessed by summing the time spent in moderate and vigorous PA. MVPA was taken as a measure of high intensity activity.

Inhibition involves the ability to control attention and behavior on the task at hand, while suppressing attention to other stimuli (Diamond, 2013). Inhibition skills were tested with the Golden version of the Stroop test (Buck et al., 2008), in which the child has to complete three reading conditions in 45 seconds each. In the first condition (Word card), the child has to read out aloud words written in black ink (e.g. green, yellow). In the second condition (Color card) the child has to name the colors of colored rectangles. In the last condition (Color-Word card), the child is presented with words written in different colors of ink, and is asked to name the color of the ink instead of reading the word (e.g. green written in blue ink). In all three conditions, the number of correctly mentioned items is scored. In order to get a measure of their inhibition skills, a ratio score ($I_R$) was calculated by dividing the score of the third condition by the score of the second condition; $I_R = CW/C$ for number of items scored. This is a method to assess the resistance to interference, independently of the child's ability to read or name colors (Lansbergen, Kenemans, & Van Engeland, 2007). A higher ratio score indicates a better ability to resist interference. The Golden version has been used in children from age 5. Test-retest reliability coefficients of the three separate cards are high ($r > 0.80$) (Neyens & Aldenkamp, 1997; Strauss, Sherman, & Spreen, 2006).

Working memory involves the ability to hold and manipulate information in the mind (Diamond, 2013), which was assessed with the Visual Memory Span (VMS) test, a part of the Wechsler Memory Scale revised (Wechsler, 1987). In the VMS test a child has to replicate a sequence of movements of the examiner who is pointing at colored squares on a paper, in a predefined order. The tests starts with two sequences and increases to seven sequences that the child has to copy in reverse (backward) order, 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. Each correct trial is awarded with one point. The maximum score for the VMS test is 12 points, with a higher score indicating better performance. The VMS test has been used in children from age 6. Reliability of working memory tests similar to the one adopted here, ranges from 0.70 to 0.90 (Strauss et al., 2006).

Cognitive flexibility, which is the ability to change attention and switch rapidly between response sets (Anderson, 2002), was measured using the Trailmaking test
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(TMT). This is a paper and pencil task containing two parts. In trail A the child is asked to connect circles in numerical order, while in trail B the child has to alternate between both numerical and alphabetical order, by drawing a line from one point to the next as quickly as possible (Reitan, 1971). To obtain an accurate measure of cognitive flexibility, 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, and shows low (Trails A, $r = 0.33$) to moderate (Trails B, $r = 0.56$) test-retest reliability (Neyens & Aldenkamp, 1997; Strauss et al., 2006).

Planning ability was measured using the Tower of London (ToL) test (Shallice, 1982). In the ToL 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. This implies that the child creates a strategy to solve the problem and keeps in mind the target pattern while evaluating the progress after each move. A total of 12 problems have to be solved that vary in difficulty by the number of required moves, starting with two and increasing to five moves. Only one ball can be moved at a time, and cannot be moved when another ball is lying on top of it. Besides, the longest peg can carry three balls, the middle peg two and the shortest peg one ball. A problem is solved correctly when the target pattern is achieved in the prescribed number of moves. The child has three attempts to solve each problem and receives points accordingly: three points when the problem has been solved in one attempt, two if two attempts were necessary and one if the child needed three attempts to solve the problem. No points are given if the child does not succeed to solve the problem in three attempts. The ToL score is the sum of points of all 12 problems, resulting in a maximum score of 36. In addition, decision time and execution time were scored to investigate the processes underlying ToL performance. Decision time is the time between the presentation of the problem and the initiation of the first move of a trial (ball leaves peg), while execution time is the time between the first move and the completion of the trial (regardless of the (in)correctness of the moves) (Anderson, Anderson, & Lajoie, 1996). The sum of the decision times of the first trial of all 12 problems was used as total decision time score, and the sum of the execution times of the first trial of all 12 problems was used as total execution time. The ToL has been tested and validated for use with children from age 7 (Anderson et al., 1996).

Data analyses were performed using SPSS 20.0 for Windows (IBM Corp., Armonk, NY, USA). In nine cases, data for ToL execution time was missing. These data were replaced by the regression means of the missing value analysis of SPSS (standard error of
the estimate = 0.13). Pearson’s partial correlation coefficients \((r)\) between the PA variables and executive functioning measures were calculated, adjusting for gender, age, SES and total wear time. For the Stroop ratio score, the correlation was also adjusted for the score on condition one (Word card), to control for the reading proficiency of the child. Cohen’s conventions to interpret the strength of the correlations were used, with a correlation of 0.1 representing a small association, 0.3 as moderate, and 0.5 or larger representing a strong association (Cohen, 1992). \(P\)-values < .05 were regarded as significant.

3.3 Results

Three children were excluded from the analyses as their MVPA measure was more than 3 standard deviations above the median, bringing the total sample to 77. Table 3.2 shows the results on the PA variables and performance on executive functioning measures for all participants. A Student’s t-test revealed that boys spent significantly more time (52 ± 14 min/day) at a moderate to vigorous intensity level than girls (37 ± 14 min/day). No significant differences between boys and girls were found on the other PA measures, and on performance of all executive function measures.

Table 3.2. Results for the physical activity and executive functioning measures for the total sample.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical Activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total PA (counts/min)</td>
<td>526</td>
<td>127.9</td>
<td>237.3 – 812.5</td>
</tr>
<tr>
<td>Sedentary behavior (min/day)</td>
<td>366</td>
<td>70.0</td>
<td>222.0 – 570.8</td>
</tr>
<tr>
<td>MVPA (min/day)</td>
<td>43</td>
<td>15.8</td>
<td>11.0 – 80.2</td>
</tr>
<tr>
<td><strong>Executive Functioning</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop (ratio)</td>
<td>0.65</td>
<td>0.11</td>
<td>0.40 – 0.90</td>
</tr>
<tr>
<td>VMS (points)</td>
<td>6.8</td>
<td>1.6</td>
<td>2 – 10</td>
</tr>
<tr>
<td>TMT (s)</td>
<td>83.2</td>
<td>40.5</td>
<td>23 – 245</td>
</tr>
<tr>
<td>ToL (points)</td>
<td>27.5</td>
<td>3.2</td>
<td>19 – 35</td>
</tr>
<tr>
<td>ToL dec time (s)</td>
<td>58.1</td>
<td>37.8</td>
<td>21.7 – 288.9</td>
</tr>
<tr>
<td>ToL exe time (s)</td>
<td>135.7</td>
<td>49.5</td>
<td>76.0 – 368.5</td>
</tr>
</tbody>
</table>

Note. \(n = 77\). * Student’s t-test. dec time = total decision time. exe time = total execution time. MVPA = moderate to vigorous physical activity. PA = physical activity. Stroop = Stroop color word test. TMT = Trailmaking test. ToL = Tower of London. VMS = Visual memory span test.
Table 3.3 shows the correlations between the various PA measures and scores on the measures of executive functioning for all participants. A small negative correlation was found between the time spent in sedentary behavior and the Stroop ratio score \((r = -0.24)\), indicating that children who spent a lot of time sedentary showed worse performance on this inhibition task. Significant small to moderate correlations were found between the total volume of PA and both ToL score \((r = 0.24)\) and the total execution time of the ToL \((r = -0.29)\), indicating that the more active the child, the better his or her performance on solving ToL problems, as well as the faster the child can solve ToL problems once the trial has been initiated. Also, a significant small to moderate correlation was found between time spent in MVPA and the total execution time of the ToL \((r = -0.29)\), indicating that the more time a child is active at moderate to vigorous intensities, the faster the child can solve ToL problems once the trial has been initiated. The other correlation coefficients did not reach significance.

Table 3.3. Correlations between physical activity measures and measures of executive functioning for all participants.

<table>
<thead>
<tr>
<th></th>
<th>Stroop(^a)</th>
<th>VMS(^a)</th>
<th>TMT(^b)</th>
<th>ToL(^b)</th>
<th>ToL dec time(^a)</th>
<th>ToL exe time(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PA</td>
<td>0.11</td>
<td>0.04</td>
<td>-0.04</td>
<td>0.24(^*)</td>
<td>0.11</td>
<td>-0.29(^*)</td>
</tr>
<tr>
<td>Sedentary behavior</td>
<td>-0.24(^*)</td>
<td>-0.04</td>
<td>0.06</td>
<td>-0.17</td>
<td>ns</td>
<td>-0.12</td>
</tr>
<tr>
<td>MVPA</td>
<td>-0.09</td>
<td>0.08</td>
<td>0.01</td>
<td>0.22</td>
<td>0.03</td>
<td>-0.29(^*)</td>
</tr>
</tbody>
</table>

Note. \(n = 77\). \(^a\) A higher score indicates a better performance. \(^b\) A lower score indicates a better performance. dec time = total decision time. exe time = total execution time. MVPA = moderate to vigorous physical activity. ns = non-significant. PA = physical activity. Stroop = Stroop color word test. TMT = Trailmaking test. ToL = Tower of London. VMS = Visual memory span test.

\(^*\) Significant r-value, \(p < .05\)

3.4 Discussion

The aim of this study was to relate daily PA in typically developing children to performance on a wide executive functioning array of tasks. We found positive relations between total volume of PA and planning performance on the ToL. In addition, a negative relation was found between sedentary behavior and inhibition as measured with the Stroop test, indicating that the more time children spent in sedentary behavior, the worse their performance on this inhibition task. To our knowledge, this is the first study that shows that sedentary behavior was negatively related to performance on an executive functioning
task. There is some evidence of training studies showing that challenging, yet sedentary games could improve inhibition and working memory in children with ADHD (Best, 2010; Klingberg et al., 2005). The negative relation found in the present study suggests that the daily sedentary behavior of the current sample of typically developing children - which mainly consisted of watching TV, reading or playing on the computer - is not challenging enough to stimulate their inhibition skills. To improve executive functioning, there should be an increment in task difficulty, which might be lacking during most of the time children spent sedentary (Diamond & Lee, 2011).

The positive relation found between total volume of PA and planning performance is in line with findings from a study by Gapin and Etnier (2010), who showed that PA was positively related to performance on the ToL in boys with ADHD. Moreover, our study showed that MVPA was related to faster execution times on the ToL, which was also found by Gapin and Etnier (2010). A faster execution time indicates that, once the trial has been initiated, the child is faster in solving the problem. This can be the result of a better ability to monitor the process while moving the balls, suggesting that the task has been planned adequately in advance (Unterrainer et al., 2004). The ToL is a measure of planning and problem solving skills, but also includes abilities such as inhibition and working memory, as the child has to plan the appropriate response and inhibit task irrelevant responses. This is why Diamond (2013) calls planning a higher order executive functioning task. Perhaps the relationship between PA and executive functioning is most notable in skills that require these higher order executive functions.

Another important finding of this study was the positive relation between the total volume of PA and planning skills. This is in contrast to the finding of Booth et al. (2013), who found that total volume of PA led to lower prediction of executive function performance in adolescent children. In our study, as well as the study by Booth et al. (2013), the total volume of PA consisted mainly of light intensity exercise, suggesting that it is important to investigate what children do when they exercise at a light intensity. Children are often engaged in physically and socially playful activities of low intensity that place a demand on their executive functioning. PA of children is thus often an inherently cognitive process, stimulating executive functioning directly. The degree of cognitive engagement varies between activities and across ages (Best, 2010), which implies that the relative contribution of PA in the development of executive functioning might change as a result of experience.
A strength of the present study was that PA was measured with accelerometers, which gives an accurate reflection of what children normally do. However, when measuring PA with accelerometers, it is still not possible to capture all activities, e.g. cycling and swimming, which can lead to an underestimation of the measured PA. Besides, accelerometry does not provide information on the specific types of PA or sedentary behavior of children, which is an important area for further investigation. Also, while this study used multiple measures for executive functioning, examining the assessment procedure over sessions would strengthen the reliability, as well as including more indices of each executive functioning. Nevertheless, this study reveals independent and opposing relationships between sedentary and active behavior and some important executive functioning in children, which supports interventions to decrease sedentary time.

3.5 Conclusion

Children should try to limit their time spent in sedentary behavior, while increasing their overall PA as well as the time spent in MVPA. More research is needed to study whether sedentary behavior counteracts the positive relation between MVPA and executive functioning. Also, getting more insight into both the quantity and quality of PA in children is needed to identify whether certain types of PA are more strongly related to executive functioning than others.

Practical implications

- Children's daily PA gives a reflection of the activity pattern of children during everyday life, including time spent in sedentary behavior.

- More time spent in sedentary behavior is associated with worse performance on inhibitory control in children.

- Children should be challenged to be more physically active, either in low or high intensity activities, as this is positively associated to their planning performance.
References


