

ORIGINAL ARTICLE

The effects of a school-based physical activity intervention programme on children's executive control: The Health Oriented Pedagogical Project (HOPP)

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Aims: To assess the effects of a large school-based physical activity intervention on children's ability to resist distractions and maintain focus, known as executive control. **Methods:** A quasi-experimental design with seven intervention and two control primary schools. The Health Oriented Pedagogical Project (HOPP) intervention consisted of 45 min of physical activity a day during school time for 6–8 months in addition to the regular weekly physical education lessons. A total of 1173 children, spanning from second grade (age 7 years) to sixth grade (age 12 years) were included in the analysis. Main outcome measures were executive control was measured at baseline and 1 year after using a modified Eriksen flanker task for the younger children (second and third grades) and a computerised Stroop task for the older children (fourth, fifth, and sixth grades). **Results:** Both the intervention and control group showed improvements in executive control after 1 year. However, the children in the intervention group did not improve their performance more than those in the control group. **Conclusions:** No positive effect of the physical activity intervention programme on children's task performance was found, suggesting that the intervention did not affect children's executive control.

Keywords: *Executive control, intervention, executive function, exercise, cognitive control, physical activity, preventive health services, school, children*

Background

There is a growing concern that children are less physically active and more sedentary than recommended [1–3]. Children are 40% less active than they were 30 years ago, likely due to the increased use of technology in the home and motorised transport [4–7]. Physical inactivity in children has caused a rise in childhood obesity, which is associated with hypertension, coronary heart disease, and type 2 diabetes mellitus in adulthood [8–11]. A sedentary lifestyle in childhood not only influences physical health throughout the lifespan, it also affects aspects of cognitive and psychosocial development, including attention, memory and self-esteem [12–14].

Prior studies have reported the benefits of physical activity on cognition in children. For instance,

meta-analyses investigating the effects of physical activity in school-aged children have found a positive relationship between physical activity and perceptual skills, intelligence quotient (IQ), academic achievement, school readiness, mathematical tasks, verbal tasks, reading ability, and other abilities such as creativity [15, 16]. A recent meta-analysis furthermore found that physically fit children perform better on cognitive tasks compared to less fit children, that children's brain structure and function demonstrate fitness-related differences, and that higher physical activity is predictive of better cognitive performance [14].

Physical activity has generalised effects on cognition; however, some cognitive functions are more

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influenced by physical activity than others [17]. In a cross-sectional study of 241 individuals aged 15–71 years, Hillman et al. [18] investigated the relationship between physical activity and general and selective aspects of cognition. Results showed that physical activity was associated with general cognitive performance. However, the largest associations were found for tasks requiring high amounts of focus and inhibition of irrelevant responses, known as executive control [19]. A meta-analysis by Colcombe and Kramer (2003) designed to study the impact of physical activity on cognitive performance in older adults reported similar findings. Results demonstrated a moderate effect of aerobic exercise on overall cognitive performance ($g=0.48$). Further, they found that effect sizes varied depending on the type of task used, with the largest improvements found for tests of executive function ($g=0.68$) and the smallest effects found for spatial ($g=0.43$) and speed tasks ($g=0.27$). Executive function might therefore be particularly responsive to the effects of physical activity.

Executive control is considered a fundamental skill which helps us attain our goals by restraining impulses and enabling us to resist temptations [20]. Studies have shown that the ability to exert executive control improves greatly between early childhood and late adolescence [21, 22]. These improvements have been related to maturation of the prefrontal cortex and associated subcortical areas [23]. One of the most widely used experimental paradigms for studying executive control is the Stroop task [24]. In this task, participants are presented with a series of words and asked to name the colour in which each word is written. Participants generally have a longer reaction time (RT) when the colour name is written in a different coloured ink than when the colour name and ink colour match. For example, participants have shorter RTs when a green word actually spells *green* than when it spells *blue*. Most people have difficulty attending to the colour in which the word is printed due to the automated habit of reading, resulting in a slower response. This phenomenon has been termed ‘the interference effect’. Young children, whose frontal lobes have not yet fully matured, specifically have difficulties inhibiting the response to read the word and to focus their attention on the colour in which the word is written [25]. However, since the Stroop task requires proficient reading skills to induce the interference effect, this task is not suitable for younger children. Another task that has been frequently used to measure executive control is the Eriksen flanker task [26]. In this task, participants see a target stimulus (usually an arrow) with distractors on the left and right side of the target. The distractors can be congruent (arrows

that point in the same direction) or incongruent (arrows that point in another direction). Participants need to press a key button on the left when the target arrow points to the left and a key button on the right when the target points to the right. The common finding is that response rates tend to be faster, and responses more accurate, if the distractors are congruent with the target stimulus than when the distractors are incongruent with the target stimulus. Since this task does not require any verbal skills, it can be used to measure executive control in younger children. Hillman et al. [17] used the flanker task to investigate the relationship between aerobic fitness and executive control in children and found that fitness was positively related to response accuracy. Similarly, greater aerobic fitness has also been found to be associated with better performance on the Stroop task [27].

Although several studies have linked physical activity to improvements in executive control, much is still unknown about the underlying mechanisms that link physical activity to improved cognitive function. However, it has been proposed that physical activity increases oxygen saturation in brain areas related to executive control [28]. Physical activity has also been found to increase serotonin and norepinephrine levels, facilitating information processing [29]. Finally, it has been suggested that physical activity improves cognition by the upregulation of neurotrophins, which are proteins involved in neuronal survival and differentiation [30]. Several pathways may therefore account for the positive relationship between physical activity and executive control.

The literature on the relationship between physical activity and cognition has grown rapidly during the past decade [31]. However, the majority of physical activity studies with humans have focused on older adults and the prevention of cognitive decline [31]. Less is therefore known about the effects of physical activity on children’s executive control, which develops gradually over childhood as the prefrontal cortex matures [32]. In addition, a recent review suggests that most of the literature on physical activity and cognitive function is on cross-sectional studies, which are not suitable for verifying causal relationships [14]. Cross-sectional studies furthermore raise the possibility that observed differences between fit and less fit children are caused by unmeasured factors such as genes and personality [33]. Accordingly, controlled longitudinal studies are necessary to elucidate the effects of physical activity on executive control in children.

Schools provide a unique setting to promote health and wellbeing among children. Since the majority of children in developed countries attend

primary school, children from different cultural and socioeconomic backgrounds are easily accessible at school. Schools also have an established system and infrastructure into which interventions can be incorporated. While there are numerous opportunities for physical activity during school time, children spent on average 65% of their time at school in sedentary activities and only 5% on moderate to vigorous intensity activities [34]. Consequently, primary school prevention programmes have the unique potential to increase children's physical activity and decrease sedentary behaviour, which in turn can positively affect their health and cognitive function.

A persistent finding in physical activity research is the decline in physical activity with age. Specifically, longitudinal studies have found that the greatest decline in physical activity occurs between 12 and 18 years [35]. Although the decline in physical activity is the greatest during adolescence, a cross-sectional study by Sherar and colleagues [36] found that physical activity already starts to decline in children between 8 and 13 years. In addition, they also found that boys were more physically active compared to girls at all ages. Similarly, Ridloch and colleagues [37] measured physical activity levels in 9-year-olds and found that girls spend 20% less time in daily moderate physical activity than boys. Physical activity has not only been found to be related to age and gender in children, but also to body mass index (BMI). In a large cross-sectional study of 1292 children aged 9–10 years, it was found that body fatness was significantly associated with time spent at physical activity, with normal-weight children being more active than obese children, even after adjusting for gender [38]. Together, these studies indicate that younger children are more physically active than older children, that boys are more active than girls, and that BMI is negatively associated with physical activity.

The present study examined executive control in school-aged children (second to sixth grade, aged 7–12 years) participating in a school-based physical activity intervention compared to a non-intervention control group. Children were tested at baseline and again at 1 year. The longitudinal design of the study allowed us to extend earlier findings from correlational studies investigating the relationship between physical activity and executive control in children [17, 39–42]. The goal of the study was to investigate whether a school-based physical activity programme promotes children's executive control by increasing physical activity levels throughout the school day. It was predicted that children in the intervention group would show greater post-test improvements on tasks requiring executive control compared to the non-intervention control group. In addition, we expected certain groups who are

less active to benefit more from the intervention than other groups. First, based on the literature described above, we predicted that the intervention would have a greater effect on the oldest children, who are less physically active than younger children. Second, we predicted a larger effect for girls compared to boys, since boys at this age are more physically active than girls. Finally, we predicted that the intervention would have a greater effect on children with a high BMI than those children with a low or normal BMI.

Method

Participants

Nine primary schools participated in the project. Seven of them (located in Vestfold County, Norway) received the intervention, while the other two schools (located in Akershus County) served as a control. The intervention schools were recruited from Horten municipality. All primary schools in the municipality participated. The control schools were recruited based on estimated socioeconomic level, using a centralised Norwegian programme called PULS [43]. From the total population of 2817 pupils, 2297 pupils (82%) from first to sixth grade (age 6–12 years) agreed to participate at baseline. Only participants who completed an executive control task at baseline and 1 year after the start of the intervention were included in the analysis, resulting in a total of 1173 participants (793 in the intervention group and 380 in the control group) spanning from second grade (age 7 years) to sixth grade (age 12 years). This number is significantly lower than the 2297 pupils who agreed to participate since executive control was not assessed at each grade (see also 'Measures' for a description of the type of task used for each age group). Table I lists participant characteristics. The gender distribution was 395 girls (49.8%) in the physical activity intervention group and 200 girls (52.6%) in the control group.

Design

The study used a quasi-experimental design. The measures reported in this study were collected at baseline (pre-intervention) and 1 year later (post-intervention). The study was conducted in accordance with the Declaration of Helsinki (2013). The Regional Committee for Medical Research Ethics approved the study protocol (2014/2064/REK south-east). Informed consent was obtained from parents or guardians prior to testing. For more detailed information about the project, see Fredriksen et al. [44].

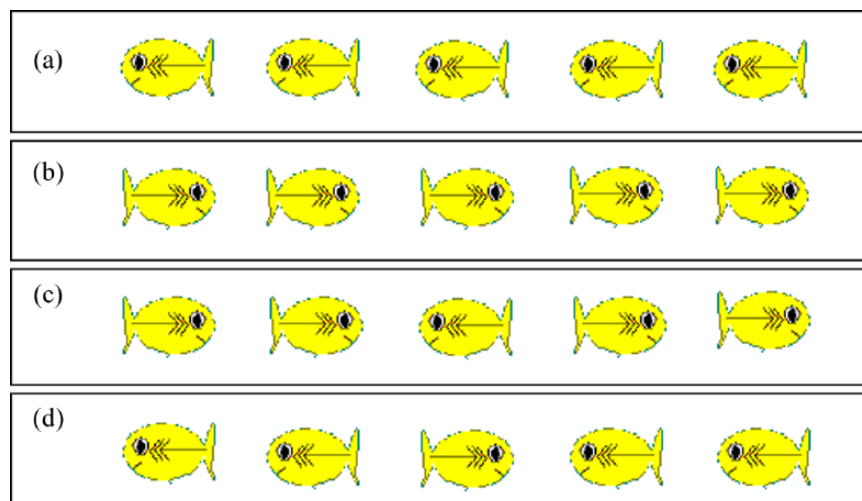


Figure 1. Trials used in the Flanker task: (a) congruent left; (b) congruent right; (c) incongruent left; (d) incongruent right.

Intervention

The Health Oriented Pedagogical Project (HOPP) intervention consisted of 45 min of physical activity a day, replacing ordinary desk learning with physical tasks. In Norway, organised physical activity during primary school consists of 90 min weekly of physical education lessons. Hence, the pupils in the intervention schools received an additional 225 min of physical activity a week. A working group of 14 experienced teachers in Horten municipality with special interest and education in health promotion and physical activity, as well as pedagogical experience, designed the intervention. The intervention was based on Harter's Competence Motivation Theory, which is achievement motivation based and founded on a person's feelings of personal competence [45]. The activities in the intervention were adjusted for grade level and aimed to have moderate to high intensity level, with 25–30% of the time at a vigorous activity level. Prior to the intervention, all teachers from the intervention schools received a 2-day training course led by the working group to teach them how to incorporate physical activities in their language and math courses. Based on a library of activities in a toolbox designed particularly for this intervention, teachers decided individually when and how the activity lesson should be conducted. As morning sessions in primary school typically last 90 min before recess, a typical lesson consisted of 45 min of theory in the classroom, followed by 45 min with active learning. The activities were performed in the schoolyard, gymnasium, or school halls.

Measures

Based on the age of the participant, executive control was measured at baseline and 1 year after using one of two tasks. The younger children (second and third grades) performed a modified computerised Eriksen flanker task, while the older children (fourth, fifth, and sixth grades) performed a computerised Stroop task. Stimuli were presented on a laptop using Inquisit 4.0 software (Millisecond Software, Seattle, WA, USA). Children were seated approximately 50 cm from the monitor. Body height, weight, and BMI were measured barefooted, in light clothing, using an electronic scale (Tanita MC-980MA, Tokyo, Japan). To compensate for the weight of clothes, 0.4 kg was withdrawn from the total weight. Parental education level was measured with a questionnaire and scored based on the highest completed educational level (1-primary school, 2-high school, 3-bachelor's degree, 4-master's/PhD degree).

Flanker task

A modified version of the Eriksen flanker task was used to measure executive control in the youngest children, aged 7–8 years [26]. In this task, children were shown a line with five identical fish, with the central fish being the target, and the ones on the sides being flankers (see Figure 1). The children were instructed to focus on the central fish and to press the arrow key corresponding to the fish's orientation. The task had two types of trial: congruent and incongruent trials. In the congruent trials, the five fish were oriented in the same direction, while in the incongruent trials, the flanker and target animals were oriented in

Table I. Mean values (SD) for participant demographics by participant group.

| | Physical activity group | Control group |
|--------------------------|-------------------------|-----------------|
| <i>n</i> | 793 (395 girls) | 380 (200 girls) |
| Age (years) | 9.9 ± 1.5 | 10.6 ± 1.5* |
| Height (cm) | 141.0 ± 10.6 | 145.0 ± 10.9* |
| Weight (kg) | 35.1 ± 9.6 | 36.7 ± 8.9* |
| BMI (kg/m ²) | 17.4 ± 2.9 | 17.2 ± 2.5 |
| Maternal education (1-4) | 2.8 ± 0.8 | 3.3 ± 0.7* |
| Paternal education (1-4) | 2.7 ± 0.8 | 3.3 ± 0.8* |

BMI: Body Mass Index; * *t*-test, $p < .05$.

opposite directions. The children were shown a total of 120 trials (60 congruent, 60 incongruent), which were randomly sampled. Each trial was presented for 3000ms, with an interstimulus interval of 1500ms. The children had a 1 min break after every 40 trials. In order to get familiar with the task all participants started with a practice task with a total of 40 trials, including single fish trials, congruent trials, and incongruent trials. Participants had 3000ms to respond to each trial. If no response was recorded during this time, the message ‘too slow’ appeared on the screen.

Stroop task

A computerised version of the Stroop task was used to measure executive control in the older children, aged 9–12 years [24]. Children were shown a series of stimuli (i.e. words or solid squares) presented in either blue, green, red or black. They were instructed to identify the colour of the stimulus presented as accurately and quickly as possible by pressing one of four keys that represented each of the four colours. A total of 84 trials were presented in random order, consisting of congruent stimuli (the name of the colour matched the colour in which the word was written), incongruent stimuli (the name of the colour did not match the colour in which the word was written), and control stimuli (a coloured square). Each trial was presented until a response was given. In the case of an incorrect response, a black cross appeared on the screen.

Data analysis

All data were analysed using the statistical software package IBM SPSS Statistics version 24 (SPSS Inc., Chicago, IL, USA). Comparisons of baseline characteristics between the intervention and control group were made using a χ^2 test and two-tailed Student’s *t* test where appropriate. Both in the flanker and Stroop tasks, a conflict score was calculated by subtracting the RT of the congruent trials from the RT

of the incongruent trials (Interference Score = RT incongruent – RT congruent). A larger conflict score reflects a greater interference effect, while lower scores indicate a faster and more efficient processing of conflict [24]. Only trials with RTs equal to or larger than 200 ms were included as shorter responses are considered prepotent responses [46]. Trials with no response were categorised as omissions and excluded from analysis. Intervention effects were calculated using repeated measures analysis of covariance (ANCOVA). To adjust for baseline differences between groups, test outcome was analyzed using an analysis of covariance model with age and parental education level as covariates. Height and weight were strongly correlated with age and were therefore not included as covariates.

Results

Participant characteristics

Participant baseline characteristics are provided in Table I. Between-subject *t*-tests revealed that the physical activity intervention group differed from the control group on age, height, weight and parental education level, all $p < .001$. No group differences were found for BMI, $p > .05$. Pearson product-moment correlations revealed a negative relationship between age and RT on the Flanker and Stroop tasks and error rate on the Stroop task, all $p < .05$. Furthermore, maternal education was found to have a negative relationship with the error rate on the flanker task, $p < .01$. BMI did not correlate with the outcomes of either the Flanker or the Stroop task, all $p < .05$. There was a significant gender effect on the Stroop, but not on the Flanker task, with girls having slower responses and fewer errors than boys, $p < .05$.

Task performance

Table II shows the mean RTs and error rate for the physical activity and control group on the Flanker and Stroop tasks. To examine the efficacy of the Flanker and Stroop tasks in eliciting the interference effect, performance differences between the different conditions were investigated in the entire sample. In both the Flanker and Stroop tasks, there was a significant effect of flanker type on RT ($F(1, 920) = 428.02$, $p < .001$, $\eta^2 = .32$ and $F(1, 2009) = 315.29$, $p < .001$, $\eta^2 = .14$, respectively) and the amount of errors made ($F(1, 920) = 179.94$, $p < .001$, $\eta^2 = .16$ and $F(1, 2009) = 343.54$, $p < .001$, $\eta^2 = .15$). Children had more difficulty with the incongruent trials versus the congruent trials, as indicated by a longer RT for incongruent trials (Flanker $M = 991.3$ ms, $SD = 265.5$ ms; Stroop $M = 1960.0$ ms, $SD = 792.9$ ms) compared to

Table II. Mean task performance (SD) for the physical activity and control groups at pre- and post-test.

| | Physical activity group | | Control group | |
|---------------------|-------------------------|----------------|----------------|----------------|
| | Pre-test | Post-test | Pre-test | Post-test |
| <i>Flanker task</i> | | | | |
| Mean RT (ms) | | | | |
| Congruent trials | 889.5 ± 214.1 | 822.46 ± 192.0 | 882.4 ± 210.2 | 743.2 ± 131.3 |
| Incongruent trials | 999.0 ± 278.9 | 900.7 ± 230.4 | 969.1 ± 222.0 | 794.9 ± 138.6 |
| Errors (%) | | | | |
| Congruent trials | 7.0 ± 8.9 | 5.0 ± 6.4 | 5.2 ± 9.5 | 2.4 ± 3.4 |
| Incongruent trials | 13.6 ± 14.5 | 10.4 ± 12.6 | 9.8 ± 15.1 | 4.4 ± 4.3 |
| <i>Stroop task</i> | | | | |
| Mean RT (ms) | | | | |
| Congruent trials | 1660.8 ± 637.5 | 1373.4 ± 467.3 | 1592.0 ± 639.2 | 1322.6 ± 509.8 |
| Incongruent trials | 1981.5 ± 809.8 | 1635.4 ± 620.6 | 1921.5 ± 763.5 | 1554.2 ± 632.5 |
| Control trials | 1685.8 ± 624.2 | 1374.8 ± 452.4 | 1592.9 ± 589.4 | 1370.2 ± 585.0 |
| Errors (%) | | | | |
| Congruent trials | 4.1 ± 5.7 | 4.2 ± 6.5 | 4.1 ± 6.1 | 3.7 ± 6.3 |
| Incongruent trials | 10.9 ± 11.1 | 8.5 ± 8.9 | 10.8 ± 11.3 | 8.0 ± 8.7 |
| Control trials | 5.0 ± 6.7 | 4.9 ± 6.9 | 4.5 ± 6.5 | 4.2 ± 5.9 |

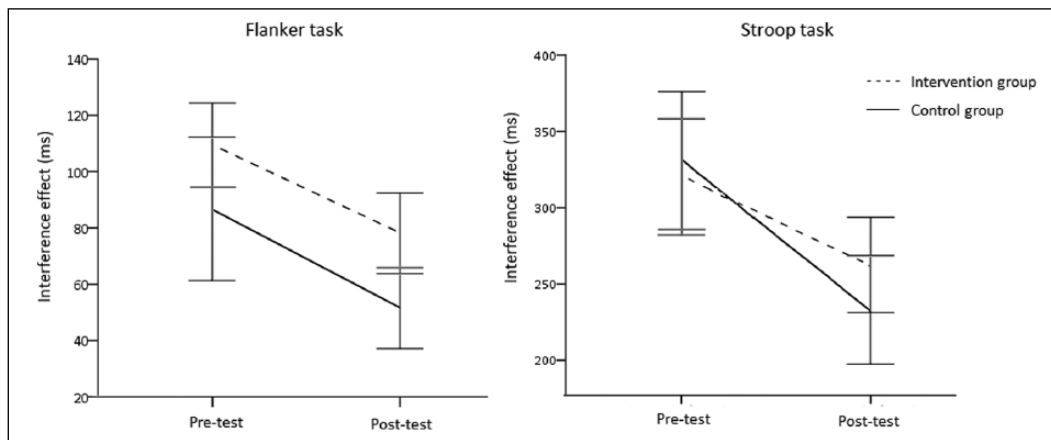


Figure 2. Mean interference effect at pre- and post-test for the physical activity intervention group and control group. Error bars represent 95% confidence intervals.

congruent trials (Flanker $M=887.7$ ms, $SD=212.8$ ms; Stroop $M=1636.8$ ms, $SD=637.3$ ms). Similarly, children made more errors on the incongruent trials (Flanker $M=12.6\%$, $SD=14.7\%$; Stroop $M=10.8\%$, $SD=11.1\%$) compared to the congruent trials (Flanker $M=6.5\%$, $SD=9.1\%$; Stroop $M=4.1\%$, $SD=5.8\%$). Consequently, both the Flanker and Stroop tasks were effective in eliciting the interference effect.

Children had a shorter RT on the post-test (Flanker $M=838.0$ ms, $SD=193.5$ ms; Stroop $M=1482.0$ ms, $SD=525.9$ ms) compared to the pre-test (Flanker $M=939.5$ ms, $SD=234.2$ ms; Stroop $M=1798.4$ ms, $SD=683.2$ ms), Flanker main effect of time, $F(1, 281)=40.02$, $p<.001$, $\eta^2=.13$, Stroop main effect of time, $F(1, 911)=317.98$, $p<.001$, $\eta^2=.26$. Similarly, they made fewer errors on the post-test (Flanker $M=6.6\%$, $SD=7.9\%$; Stroop

$M=6.2\%$, $SD=6.8\%$) compared to the pretest (Flanker $M=9.6\%$, $SD=10.9\%$; Stroop $M=7.5\%$, $SD=7.1\%$), Flanker main effect of time, $F(1, 281)=17.47$, $p<.001$, $\eta^2=.06$, Stroop main effect of time, $F(1, 911)=19.60$, $p<.001$, $\eta^2=.02$.

Intervention effect

Figure 2 shows the interference effect on the Flanker and Stroop tasks for the intervention and control group. A main effect for session (pre vs post), $F(1, 280)=11.21$, $p<.001$, $\eta^2=.04$ and group (intervention vs control), $F(1, 280)=6.23$, $p=.01$, $\eta^2=.02$ was found on the interference effect of the Flanker task. However, no interaction effect was found, $F(1, 280)=.04$, $p=.85$, $\eta^2<.01$, indicating no significant effect of the intervention programme on the interference effect. For the Stroop task, a main effect of

session (pre vs post) on the interference effect was found, $F(1, 909) = 16.61$, $p < .001$, $\eta^2 = .02$. Group (intervention vs control) had no main or interaction effects on the interference effect, all $p > .05$.

Considering the results in terms of the two separate conditions (congruent and incongruent trials), there was a significant interaction effect for session and group on children's RT in the congruent conditions of the Flanker task, $F(1, 280) = 4.59$, $p = .03$, $\eta^2 = .02$. The control group had a larger improvement in RT (MD = -139.26 ms) than the intervention group (MD = -67.07 ms). No significant session \times group interaction effects were found on the incongruent trials or on the error rate of the Flanker task. Analysis of the Stroop task revealed no significant interaction effects involving group and session for the congruent or incongruent trials.

To test whether the intervention had differential effects across different age groups, we included an interaction term with age (year) in the analysis. No significant interaction effects were found between session (pre vs post), group (intervention vs control), and age, all $p > .05$. Similarly, no significant interaction effects were found between session, group, and gender, all $p > .05$. To test whether the intervention affected overweight children differently from normal weight children, the group was divided into two groups based on their BMI. Children with a BMI percentile $>$ 85th sex-specific percentile for age were defined as overweight and those $<$ 85th percentile as normal weight [47]. Results revealed no significant interaction effects between session (pre vs post), group (intervention vs control), and weight (overweight vs normal), all $p > .05$.

Discussion

This study examined whether a school-based physical activity programme improved executive control in a large sample of school-aged children relative to a non-intervention control group. Replicating previous findings, children performed better on congruent compared to incongruent trials on the Flanker and Stroop tasks and improved their performance with age [17, 48, 49]. These results indicate that tasks requiring interference control are more cognitively challenging, resulting in poorer performance. However, contrary to our expectation, we did not find that the physical activity intervention programme had a positive effect on children's task performance, suggesting that the intervention did not affect children's executive control.

Previous studies have found a negative association between age and physical activity [50, 51]. Physical activity programmes might therefore be more effective for older children who engage in less physical

activity than younger children. However, the present results did not support this hypothesis, as age did not influence the effect of the intervention on children's executive control. The hypothesis that girls, who engage less in physical activity than boys, might benefit more from the intervention than boys was also not supported by the results from the study. BMI has previously been found to be negatively related to physical activity in school-aged children [52]. Consequently, physical activity programmes are likely to influence children with a high BMI more than children with a low BMI, who might already engage in regular physical activity. However, our results did not find support for this hypothesis, as the intervention programme did not affect the executive control performance of overweight children either. A potential reason for why the intervention did not successfully increase children's executive control might be that Norwegian children are already relatively physically active. For instance, it was found that 83.2% of the 9-year-old children in Norway fulfil the recommendations of 60 min of moderate physical activity daily, compared to 42.0% of children in the United States [53, 54]. Similarly, a systematic review of school-based interventions focusing on physical activity levels found that the mean baseline BMI of the 23 studies included in the analysis ranged from 15.5 to 27.6 kg m⁻². The average BMI of the children included in the current study was 17.3 kg m⁻². Consequently, the children had a relatively low BMI compared to children included in other studies. This could explain why the intervention did not show similar effects as other studies.

Several previous studies have reported an effect of physical activity on children's executive control. For instance, Hillman et al. [17] investigated the relationship between aerobic fitness and executive control in 19 more fit and 19 less fit school-aged children. Participant performed a flanker task on which the more fit children exhibited greater response accuracy compared to the less fit children. However, no group differences were found on RT, with both groups exhibiting an equal increase in RT to incongruent compared to congruent trials. It is important to note that this study had a cross-sectional design. Differences in response accuracy may therefore have been caused by factors other than fitness level. For instance, differences in children's level of motivation and parental encouragement might also have influenced results. In another study, Chaddock-Heyman et al. [33] investigated the effects of a 9-month physical activity programme on executive control performance and task-evoked brain activation in 8–9-year-old children using a modified flanker task. Results revealed that the intervention group had shorter RT for the incongruent trials at post-test relative to pre-test, while no

significant effect was found for a wait-list control group. In addition, the children in the intervention group showed decreases in fMRI activation in the right anterior prefrontal cortex following the intervention, whereas activation patterns remained unchanged in the control group. However, no intervention effects were found on response accuracy, and the sample size of the study was rather small, including 24 children in the intervention group and 9 in the wait-list control group. Therefore, the effects of physical activity on children's executive control have not yet been clearly demonstrated.

A review by Keeley and Fox [55] on the impact of physical activity and fitness on children's cognition and academic achievement reported that there are relatively few published studies in the field and that the majority of studies are cross-sectional and correlational in design. Furthermore, they found that these studies produced at best weak positive associations and that none of the intervention studies supported a link between physical activity and children's academic or cognitive performance. The results of the present study support the view of this review suggesting that physical activity intervention programmes might not improve children's cognitive performance.

A randomised control study by Davis et al. [56] investigated the effects of aerobic exercise on the cognitive functioning of overweight children. They randomly assigned school-aged overweight children to either a low-dose exercise treatment (20 min, five times a week for 15 weeks) or a high-dose exercise treatment (40 min, five times a week for 15 weeks), or to a no-exercise control condition. Results revealed a significant effect of exercise on cognition; however, this effect was only observed in the group receiving the high-dose exercise treatment, suggesting a threshold effect. It is possible that the school-based intervention programme in the current study did not reach this threshold and therefore did not find any positive effects on children's cognition. Although it includes 45 min of moderate to high intensity level exercise a day (in addition to regular physical activity), the exercises generally only lasted around 15 min each. Consequently, the intervention included mainly physical activity sessions with a short duration.

Several limitations need to be recognised. First, the children in the intervention group were not followed up individually. As such, individual intensity levels and absence from school were not recorded. Second, although two teachers at each school held follow-up courses to ensure the intervention was implemented adequately, teachers were not monitored during the physical activity sessions. It is therefore possible that not all teachers implemented the intervention procedure as instructed. However,

teachers did complete a daily questionnaire regarding the number of minutes of activity and intensity of each class in order to ensure that the children in the intervention group received the right amount of extra physical activity. Third, as can be seen in Figure 2, the control group had a better baseline executive control score on the Flanker task compared to the intervention group. Although the study did not investigate group differences directly, but compared change in task performance, it is still possible that initial group differences affected outcome. However, the baseline executive control score was similar for the two groups on the Stroop task for which no intervention effects were found either. Fourth, the physical activity tasks replaced ordinary desk learning. It is unknown how this reduction in ordinary desk learning might have affected children's learning and development in this study. For instance, the physical activity tasks might have had a positive effect on children's cognition, but might also have taken away learning time, which could have cancelled out the effects.

Conclusion

In summary, the present study did not find support for the view that increasing curricular-based physical activity improves executive control in children. Randomised controlled trials are needed to fully evaluate the effects of physical activity interventions on children's executive control. Furthermore, studies will need to investigate the effects of different types of interventions, including interventions delivered across both the school and home settings.

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