

The acute effects of two types of physical activity in physical education on response inhibition and lapses of attention in children aged 8-10 years

A cluster randomized controlled trial

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This study aimed to investigate whether (1) acute physical activity has positive effects on response inhibition and lapses of attention; and (2) cognitively engaging physical activity has stronger effects on response inhibition and lapses of attention than aerobic physical activity. Children (n = 89) were randomly assigned to the aerobic or cognitively engaging intervention, or a control condition. Response inhibition and lapses of attention were measured with a stop-signal task using a pre-post design. Multilevel analysis revealed no significant beneficial effect of acute physical activity on response inhibition and lapses of attention, nor differences between the interventions. However, more time in moderate-to-vigorous physical activity (MVPA) led to better response inhibition and reduced lapses of attention. It is concluded that positive effects of acute physical activity on response inhibition and lapses of attention are dependent on the intensity and duration, without indications for differential effects of the type of activity.

KEY WORDS: Cognition, Executive functions, Exercise, Primary school children.

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Introduction

Physical education in primary schools is an ideal setting for children to engage in physical activity. In addition to the widely known positive effects of physical activity on health related fitness (Strong et al., 2005), it has also been shown to influence cognitive functions (e.g. Alvarez-Bueno et al., 2017; Donnelly et al., 2016; de Greeff, Bosker, Oosterlaan, Visscher, & Hartman, 2018). Positive effects of continuous physical activity over several weeks have been found and there is also evidence for positive effects of one single bout of physical activity, referred to as acute physical activity, on cognitive functions in children (Donnelley et al., 2016; de Greeff et al., 2018). A number of studies have investigated effects of acute physical activity in laboratory settings (e.g. Tine & Butler, 2012; Hillman et al., 2009). However, there is less insight into the effects of acute physical activity performed in ecologically valid learning environments for children, such as physical education (Donnelly et al., 2016). The present study aims to investigate effects of acute physical activity in ecologically valid learning environments for children on cognitive functions.

COGNITIVE FUNCTIONS

Cognitive functions encompass a set of mental processes that facilitates goal-directed behavior and include, among others, attention and executive functions (Donnelly et al., 2016). Attention is defined as a cognitive state in which is focused on a selection of available perceptual information (Gerrig & Zimbardo, 2002). Executive functions refer to a subset of interrelated cognitive processes that are involved in purposeful, goal directed behavior (Banich, 2009). Three core aspects of executive functions can be distinguished: working memory, inhibition, and cognitive flexibility (Diamond, 2013; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Executive functions are essential for daily life functioning, for learning something new and have shown to be strongly related to academic performance (Best, Miller, & Naglieri, 2010; Diamond, 2013).

MECHANISMS UNDERLYING EFFECTS OF ACUTE PHYSICAL ACTIVITY ON COGNITIVE FUNCTIONS

Effects of acute physical activity on cognitive functions are often explained through the physiological arousal mechanism (Audiffren, 2009).

Acute aerobic physical activity, e.g. physical activity at a moderate-to-vigorous intensity, leads to immediate neurophysiological changes in the brain, such as enhanced cerebral blood flow (Querido & Sheel, 2007) and triggers the upregulation of neurotransmitters important for cognitive functions (e.g. epinephrine, dopamine; Dishman et al., 2006; McAuley, Kramer, & Colcombe, 2004). These neurophysiological changes are assumed to lead to changes in the level of arousal and in cognitive processes that are responsible for resource allocation. Studies by Hillman et al. (2009) and Pontifex, Saliba, Raine, Picchietti, and Hillman (2013) investigated the effects of 20 minutes of acute aerobic physical activity on a treadmill in preadolescent children and found an increased P3 amplitude after aerobic physical activity, which is likely to represent the allocation of attention (Polich, 1987). This was related to better inhibition performance, therefore supporting the physiological arousal mechanism.

More recently, it is argued that physical activity with cognitive engagement enhances cognitive functions more than ‘simple’ aerobic physical activity due to increased cognitive requirements. Cognitive engagement is defined as *‘the degree to which the allocation of attentional resources and cognitive effort is needed to master difficult skills’* (Tomprowski, McCullick, & Pesce, 2015). Physical activity can be cognitively demanding either through team games that require cooperation between children, strategic play and anticipation of teammates and opponents (Best, 2010), or by cognitive demands inherent in the coordination of complex motor tasks (Best & Miller, 2010; Schmidt, Jäger, Egger, Roebers, & Conzelmann 2015b). The same brain regions (e.g. the cerebellum and the prefrontal cortex) have shown to be involved in neural circuitries important for cognitive functions and for complex motor tasks (Diamond, 2000; Serrien, Ivry, & Swinnen, 2007). Therefore, it can be hypothesized that physical activity with cognitive engagement would lead to larger beneficial effects than aerobic physical activity alone (Schmidt et al., 2015b).

EFFECTS OF ACUTE AEROBIC PHYSICAL ACTIVITY ON ATTENTION AND INHIBITION

Meta-analyses by Chang, Labban, Gapin, and Etnier (2012) and Verburgh, Königs, Scherder, and Oosterlaan (2014) have shown that an acute bout of physical activity is beneficial for cognitive functions in children. A recent meta-analysis by de Greeff et al. (2018) has shown that acute physical activity does enhance specific domains of cognitive functions. Acute physical

activity has a small to moderate effect on attention (Hedges' $g = 0.43$, $p = 0.013$) and inhibition (Hedges' $g = 0.28$, $p = 0.042$), but there was no significant effect of acute physical activity on working memory and cognitive flexibility (de Greeff et al., 2018).

Studies by Tine and Butler (2012) and Niemann et al. (2013) showed beneficial effects of a 12 minute acute bout of running at a moderate intensity on selective attention, measured with the D2 test, in 9-13 year old children. Studies by Chen, Yan, and Yin (2014), Hillman et al. (2009), and Pontifex et al. (2013) have shown positive effects of acute physical activity, performed on a treadmill or an ergometer at a moderate intensity in 8-11 year old children on inhibition, measured with the Flanker task. These results show that acute aerobic physical activity performed in laboratory settings is beneficial for attention and inhibition in children.

Effects of cognitively engaging physical activity on attention and inhibition

A study by Schmidt, Egger, and Conzelmann (2015a) investigated effects of acute cognitively engaging physical activity on attention. Improvements on selective attention were found 90 minutes after a cognitively engaging physical education lesson (coordinative exercises; 45 minutes), but not immediately after physical activity in 11-13 year old children. Pirrie and Lodewyk (2012) showed that a 60 minute physical education lesson with at least 20 minutes of moderate-to-vigorous physical activity (MVPA) increased cognitive flexibility and inhibition, but effects were dependent on test sequence. Jäger, Schmidt, Conzelmann, and Roebbers (2014) found that 20 minutes of cognitively engaging physical activity enhanced inhibition in 6-8 year old children, whereas there was no significant effect on working memory and cognitive flexibility. These studies show that acute cognitively engaging physical activity can be beneficial for cognitive functions, but that effects are dependent of factors such as the moment of testing, test sequence, and the outcome measure.

COMPARING DIFFERENT TYPES OF PHYSICAL ACTIVITY

Studies that compared acute aerobic physical activity with cognitively engaging physical activity found contradictory results for several cognitive functions. Budde, Voelcker-Rehage, Pietraszyk-Kendziorra, Ribeiro, and Tidow (2008) showed that cognitively engaging physical activity (coordinative physical activity, 10 minutes) had stronger beneficial effects on attention compared to aerobic physical activity in 13-16 years old adolescents. However, Gallotta et al.

(2015) found that 50 minutes of physical activity with cognitive engagement (basketball games with varying rules) led to significantly less improvement on selective attention compared to traditional physical activity (circuit training) and cognitive exertion alone in 8-11 year old children. Pesce, Crova, Cereatti, Casella, and Bellucci (2009) investigated differential effects of circuit training and team games (20 minutes) on free-recall memory in 11-12 year old children. Immediate enhanced recall performance was found after team games, but not after circuit training. Delayed recall performance improved after both team games and circuit training. The study by Jäger, Schmidt, Conzelmann, and Roebbers (2015) showed no effects of either physical activity games with cognitive engagement or without cognitive engagement on inhibition, cognitive flexibility, and working memory. Finally, a study by Schmidt, Benzing, and Kamer (2016) showed that a 10-minute bout of classroom-based physical activity with high or low cognitive engagement did not enhance selective attention in 11-12 year old children. The contradictory findings between the studies may be due to differences in duration, types of activity, or outcome variables. Therefore, further research is needed to compare differential effects of different types of acute physical activity on specific aspects of cognitive functions in children.

RESPONSE INHIBITION

Studies investigating the effects of acute physical activity have mainly used the Flanker task to obtain inhibition performance. Inhibition requires both the ability to cognitively suppress conflicting stimuli, which is known as interference control, and the ability to suppress planned actions that are no longer required or inappropriate, which is known as response inhibition (Nigg, 2000; Verbruggen & Logan, 2008). The Flanker task is a task to measure interference control. We are not aware of studies that have investigated effects of acute physical activity on response inhibition in children, which was therefore the aim of the present study.

A widely used task to measure response inhibition is the stop-signal task (Verbruggen & Logan, 2008). The stop-signal task consists of go trials (response execution) and stop trials (response inhibition). The analysis of performance on the stop signal task is based on the horse-race model, which assumes a competition for the fastest process between response execution and response inhibition (Band, van der Molen, & Logan, 2003). With this model, the time that is needed to stop a response execution can be calculated and this is a measure for response inhibition (Logan, 1994). A study in 19- to 24-year-old college students has shown that 30 minutes of aerobic physical activity on a treadmill (at 65-75%

of the maximum heartrate) positively influenced response inhibition (Chu, Alderman, Wei, & Chang, 2015). Additionally, a study by Zhao, Chen, Fu, and Maes (2015) has shown that a cognitively engaging physical activity game which was performed 20 minutes per day for seven days enhanced response inhibition in children. The intervention was not beneficial for interference control. This result implies that cognitively engaging physical activity may be more beneficial for response inhibition than for interference control, but the effect of *acute* physical activity on response inhibition needs to be further examined in children. This is important, as response inhibition has shown to be strongly related to math achievement and to learning-related behaviors in children (Brock, Rimm-Kaufmann, Nathanson, & Grimm, 2009).

EX-GAUSSIAN ANALYSIS

While the D2 task is widely used as a measure for attention in studies investigating effects of acute physical activity, it is worth noting that it is difficult to distinguish information processing speed from attentional performance in this task (Ginstfeldt & Emanuelson 2010; Catroppa, Anderson, Godfrey, & Rosenfeld, 2007). One way to distinguish processing speed from attention is applying an ex-Gaussian model on individual reaction time distributions of reaction time tasks (Lacouture & Cousineau, 2008). If attention is tightly focused on the goal of a task, performance will be fast and accurate. When attention is not tightly focused on the task goal, lapses of attention can occur, which will lead to overall slower responses and to a positive skewed reaction time distribution (Unsworth, Redick, Lakey, & Young, 2010). The ex-Gaussian model combines an exponential and a normal distribution. Mean processing speed is reflected in the mean of the normal distribution, and lapses of attention are reflected in the exponential component. One study investigated effects of physical activity on ex-Gaussian parameters in 6-10 year old children (Best, 2012). Physical activity (exergaming) at moderate intensity with high and low cognitive engagement led to faster processing speed, but there were no effects on lapses of attention. The author concluded that physical activity, regardless of the type of activity, has an effect on the speed to resolve a cognitive task.

THE PRESENT STUDY

Taken together, there is evidence for positive effects of acute physical activity on cognitive functions in children. Thus far, no studies have

investigated effects of *aerobic* physical activity versus *cognitively engaging* physical activity simultaneously on attention and one of the core aspects of executive functions: response inhibition. Therefore, this study aimed to investigate whether (1) acute physical activity has positive effects on response inhibition and lapses of attention and (2) response inhibition and lapses of attention benefit more from cognitively engaging physical activity than from aerobic physical activity. We hypothesize that (1) acute physical activity has beneficial effects on response inhibition and lapses of attention and (2) cognitively engaging physical activity has stronger effects on response inhibition and lapses of attention than aerobic physical activity.

Methods

PARTICIPANTS

This study was a sub-study of a cluster randomized controlled trial (RCT; “Learning by Moving”) assessing the long-term effects of aerobic and cognitively engaging physical activity. A stratified randomization for the full cluster RCT was performed at 24 primary schools in the Netherlands, including 24 grade three and 24 grade four classes (48 classes in total). Participating schools were paired based on school size. For the first school in the pair, it was randomly selected which class (grade three or grade four) served as the intervention group and which class served as the control group. Then, it was randomly determined which intervention (aerobic vs. cognitively engaging) this class received. The paired school (thus of comparable size) received the same intervention, but this intervention was assigned to the class in the other grade to balance age within and across the study groups. So, every school delivered a control group and an intervention group in grade three and four (only one of the interventions was delivered at each school).

An effect size of $d = 0.57$ was used for the power analysis of the current sub-study. This effect size was based on the meta-analysis by Verburgh et al. (2014) on the acute effects of physical activity on inhibition in children. The power analysis for research question 1 in the current study revealed that 2.6 children per class at each school had to be included from the full cluster RCT to ensure adequate power (24 schools, 48 clusters; power = 0.80; $\alpha = 0.05$; 1-tailed; intraclass correlation = 0.10; Spybrook et al., 2011). In each class, two or three children from all children with written consent for the “Learning by Moving” study were randomly selected to participate in this study. The power was therefore 0.59 for research question 2, as each intervention was provided at half of the schools (12 schools, 24 clusters; cluster size = 2.6; $\alpha = 0.05$; 1-tailed; intraclass correlation = 0.10; effect size = 0.57). A flow chart of the total number of children is shown in Figure 1. This study was approved by the ethical board of the Vrije Universiteit Amsterdam (Faculty of Behavioural and Movement Sciences), and registered in the Netherlands Trial Register (number NTR5341).

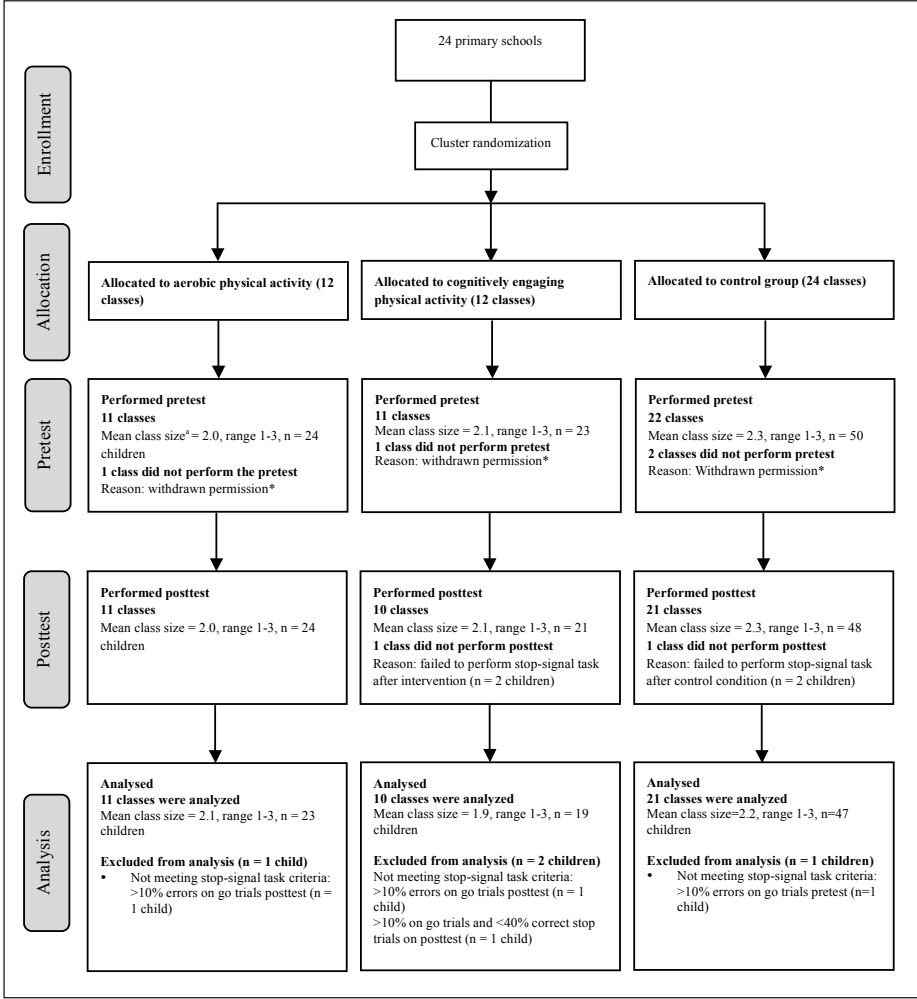


Fig. 1. - Sample size (schools and students) for enrollment, allocation, and analysis. ^aMean class size indicates the mean number of children that participated in this study per class at each school. *Two schools (four classes) had withdrawn permission after randomization, but before the start of the study due to organizational difficulties.

INSTRUMENTS

Response Inhibition

An adapted version of the stop-signal task was used to measure response inhibition (Logan, 1994). The task was performed in E-prime (version 2.0.10.356) on a laptop with a

15.6 inch monitor. The stop-signal task consisted of go trials and stop trials. On go trials (75% of trials), a drawing of an airplane was presented pointing to either the left or to the right. Children had to press one of two spatially compatible response buttons as quickly as possible after presentation of the airplane. On stop trials (25% of trials), the go-signal was followed by a stop-signal (i.e. a red traffic-sign displaying 'STOP'). Children were instructed not to press any button on stop trials, i.e. to inhibit their initial response to the go-signal. The time between the go-signal and the stop-signal, the stop signal delay (SSD), initially was 175 ms but was lengthened by 50 ms after correctly inhibited motor responses on stop-trials (increasing the difficulty of response inhibition in the next stop trial) and shortened by 50 ms after failure to inhibit the motor response (decreasing the difficulty of response inhibition in the next stop trial). Consequently, this procedure results in an average success rate at ~50% on stop trials. The task consisted of five blocks; two practice blocks and three experimental blocks. The first practice block consisted of only go trials. The second practice block consisted of 32 trials (25% stop trials). The three experimental blocks each contained 64 trials per block (25% stop trials). Data were analyzed over the three experimental blocks, providing a total of 192 trials. The stop-signal task has shown to be reliable and valid in children (Kindlon, Mezzacappa, & Earls, 1995; Oosterlaan, Logan, & Sergeant, 1998). The stop-signal reaction time (SSRT) was used as the index for response inhibition and was calculated by subtracting the mean SSD from the mean reaction time on correct go trials after excluding responses suspected of anticipatory or distracted behavior (reaction times <100 and >1500 ms; Logan, 1994; Luce, 1986).

Lapses of attention

Lapses of attention were assessed from the correct go trials of the stop-signal task. An ex-Gaussian analysis was performed in MATLAB (2018a) on the individual reaction time distribution. The ex-Gaussian model combines a normal distribution shape with an exponential component on the right side of the distribution (more background information about ex-Gaussian modeling can be found in Lacouture & Cousineau, 2008). Lapses of attention (τ) are reflected in the exponential component of the reaction time distribution. The normal distribution shape reflect the reaction time corrected for extremely slow response (μ). Relevance of the ex-Gaussian distribution has been proved in previous studies (Geurts et al., 2008; Königs et al., 2015).

Response Execution

To give more insight into the stop-signal task performance, mean reaction time on go trials, mean reaction time corrected for extremely slow responses (μ), and percentage of (omission and commission) errors were used as measures for response execution.

Internal load

Internal load of the acute physical activity interventions was measured with Polar team² heart rate monitors (Polar, 2008). The monitors stored heart rate at a frequency of 1 Hz throughout the lessons. For each child, the percentage of time in MVPA was calculated. MVPA was defined as exercise between 64 and 93% of the maximum heart rate (Howley, 2001). Maximum heart rate was estimated according to the formula by Tanaka, Monahan, and

Seals, (2001): maximum heart rate = $208 - (0.7 \times \text{age})$. If more than 20% of heart rate data were missing due to signal loss of the monitor during the measurement, data of these children were excluded (Slingerland, Oomen, & Borghouts, 2011).

PROCEDURE

Data collection took place in a pre-post design in two sessions on two separate days. During the pretest, children were taken out of the classroom and performed the stop-signal task in a quiet room in the school. During the posttest, children performed the stop-signal task after either one of the two acute physical activity interventions or after the control condition. All children performed the stop-signal task within 10 minutes after the end of the intervention or control condition. The stop-signal task was administered to the children by trained experimenters using standardized instructions. Children in the intervention groups wore Polar heart rate monitors throughout the acute physical activity session. Height and weight were measured during another physical education class.

The acute interventions were performed during a physical education lesson at primary school, in order to investigate whether positive effects of acute physical activity can be found in ecologically valid settings for children. The intervention lesson replaced their normal physical education lesson. All children in a class (on average 26 children, range: 17-31) performed the physical education lesson, independently of whether they were selected for this study or not. The interventions were provided by a certificated physical education teacher recruited for this study, who received training and a detailed description of the physical education lesson.

Aerobic intervention

The aerobic intervention consisted of individual activities targeted at an intensity of MVPA. Children had to perform repetitive exercises while they were positioned in four rows next to each other. During warming-up (10 minutes), children exercised at a slow pace. During the core phase of the physical education lesson (25 minutes), exercise was performed at higher intensity. Exercises such as running, squat jumps, and boxing were performed. The teacher demonstrated the exercises that children had to perform.

Cognitively engaging intervention

The cognitively engaging intervention consisted of specifically designed team games with cognitive engagement (Tomprowski et al., 2015). The games that were developed required strategic play and cooperation between children (Best, 2010). The lesson started with a warming-up in which the children played a version of dodge ball (10 minutes). Dodge ball requires goal-directed behavior and complex eye-hand coordination. During the core phase of the physical activity intervention (25 minutes), children played soccer and basketball. Rules of the games were adapted to enrich cognitive engagement. For example, the teacher called a number between two and six which indicated the number of players per team that had to play the game. The game they played was either soccer or basketball, dependent on the ball that was passed into the field by the teacher. The game stopped when one of the teams scored a goal or after two minutes. To ensure that the game remained cognitively demanding, a rule was added

from the moment children learned to adapt to the rules. For example, children had to touch the wall of the opponents' team before they could start the game.

Control group

Children in the control group participated in regular classroom lessons with their own teacher for 35 minutes. Seated academic activities (such as reading or mathematics) were performed.

STATISTICAL ANALYSIS

Statistical analyses were conducted in IBM SPSS Statistics version 23. First, the study groups were compared on background variables (age, sex, grade, Body Mass Index [BMI]) using ANOVA or χ^2 test, where appropriate. Secondly, an independent sample t-test was performed to compare internal load data of children in the aerobic intervention group and the cognitively engaging intervention group.

Three assumptions were checked for outcome variables of the stop-signal task (Logan, 1994). First, the percentage of correct stop trials should be around 50, since the delay value is adjusted to children's performance on the task (delay is shortened when a child fails to inhibit, and delay is lengthened when a child succeeds to inhibit). Data were considered not reliable if the percentage of correct stop trials was outside the 40-60% range. Secondly, the percentage of errors on go trials should not exceed 10% (child had not mastered the task, mean reaction time is unreliable). Third, the percentage of omission errors should not exceed 10%. When children make many omission errors, this can be a strategy (waiting for the stop signal), which would produce invalid estimations of response inhibitions. Children whose stop-signal task data did not meet these three assumptions for both pre and posttest were excluded from the analyses.

Multilevel regression analyses (MLwiN version 2.35) were used to take into account the variability between classes and nesting of children within the classes. Analyses were divided into two parts to answer the research questions. First, analyses were performed to examine differences between acute physical activity (independent of the type of physical activity) and the control condition to address the question whether acute physical activity has positive effects on response inhibition and lapses of attention. Both intervention groups were analyzed as one (acute) intervention group. Second, analyses were performed to examine the effects of both interventions separately on response inhibition and lapses of attention as compared to the control condition as well as the aerobic intervention compared to the cognitively engaging intervention.

Three models were built for each posttest stop signal task dependent variable (SSRT, τ , mean reaction time, accuracy, μ). A random intercept was calculated for each class (level 2) and each child (level 1) in each model. Model 1, the covariate model, contained only sex, grade, and corresponding pretest score as fixed effects. In Model 2, condition (intervention or control group) was added to Model 1 to assess the effect of physical activity independent of type. In Model 3, condition (control group, aerobic physical activity, or cognitively engaging physical activity) was added to Model 1 to assess the effect of type of physical activity. Model fit was calculated by comparing the deviance ($-2 \times \log\text{-likelihood}$) of Model 1 to Model 2 (for

research question 1) and Model 1 to Model 3 (for research question 2), using a χ^2 test. A false discovery rate (FDR) correction was applied to the predicted variables in the model to account for multiple testing (Benjamini & Hochberg, 1995). The FDR correction was performed separately for the dependent variables mean reaction time, accuracy, and SSRT and for the Ex-Gaussian parameters (μ and τ ; *q-values* show significance after FDR correction). Level of significance was set at 0.05 (one-sided).

Results

The final sample size consisted of 89 children with 47 participating in the control group and 42 participating in the intervention group (23 in the aerobic intervention group and 19 in the cognitively engaging intervention group; Figure 1). This resulted in a power of 0.79 for research question 1 ($\alpha = 0.05$; 1-tailed; intraclass correlation = 0.10; number of clusters: 42; average cluster size = 2; a priori effect size = 0.57). The power for research question 2 was between 0.50 and 0.55 for the underlying comparisons ($\alpha = 0.05$; 1-tailed; intraclass correlation = 0.10; number of clusters: 20 - 22; average cluster size = 2; a priori effect size = 0.57). Table I shows the demographics of the children. Table II describes the results of the stop-signal task variables for the three study groups during the pre- and posttest.

The mean duration of the cognitively engaging lessons (42.2 ± 9.1 minutes) was significantly longer than the mean duration of aerobic lessons (32.8 ± 5.7 minutes), $t = 4.2$, $p < 0.01$. However, the number of minutes spent in MVPA did not significantly differ between the two intervention groups. Children in the aerobic intervention group exercised on average $19.1 (\pm 5.7)$ minutes in MVPA and children in the cognitively engaging intervention group exercised on average $19.2 (\pm 8.2)$ minutes in MVPA. It is important to note that the inter-individual variability within the intervention groups was

TABLE I
Descriptive statistics for the included population.

	Aerobic physical activity group (n = 23)	Cognitively engaging physical activity group (n = 19)	Control group (n = 47)	p-value
Age ^a	8.81±0.6	8.77±0.6	8.82±0.6	0.95 ^c
Sex (%boys)	47.8	57.9	53.2	0.81 ^d
Grade (%3th grade)	56.5	52.6	44.7	0.62 ^d
BMI (kg/m ²) ^a	17.43±3.0	17.47±3.4	16.58±1.9	0.29 ^c
Overweight ^{b,c}	4(17.4)	4(21.1)	5(10.9)	0.18 ^d
Obesity ^{b,c}	1(4.3)	2(10.5)	0(0.0)	

^a mean(SD); ^b n(%); ^c One-way Anova; ^d Non-parametric χ^2 test; ^e based on reference values by Cole and Lobstein (2012).

TABLE II
Scores (Mean $\pm$ SD) On The Measures Derived From The Stop-Signal Task For Pre- And Posttest.

		Aerobic physical activity group (n = 23)	Cognitively engaging physical activity group (n = 19)	Control group (n = 47)	p-value
Response inhibition					
SSRT (ms)	Pretest	242.06 $\pm$ 43.3	246.27 $\pm$ 53.4	250.04 $\pm$ 45.3	0.79
	Posttest	244.73 $\pm$ 50.6	243.98 $\pm$ 43.7	245.69 $\pm$ 53.8	0.99
Lapses of attention					
τ (ms)	Pretest	133.64 $\pm$ 29.1	123.21 $\pm$ 44.9	123.97 $\pm$ 39.1	0.56
	Posttest	127.77 $\pm$ 29.9	121.82 $\pm$ 44.1	117.24 $\pm$ 42.4	0.58
Response execution					
Mean reaction time (ms)	Pretest	622.67 $\pm$ 67.8	621.85 $\pm$ 70.1	635.92 $\pm$ 69.7	0.65
	Posttest	584.37 $\pm$ 86.1	549.74 $\pm$ 73.9	572.23 $\pm$ 77.04	0.36
Accuracy (% errors)	Pretest	2.22 $\pm$ 2.0	2.43 $\pm$ 2.1	1.98 $\pm$ 1.96	0.69
	Posttest	2.16 $\pm$ 2.4	2.90 $\pm$ 2.1	1.61 $\pm$ 1.5	0.04
μ (ms)	Pretest	489.02 $\pm$ 70.1	498.64 $\pm$ 85.7	511.95 $\pm$ 84.2	0.52
	Posttest	456.59 $\pm$ 91.0	427.92 $\pm$ 59.8	454.99 $\pm$ 84.3	0.23

Lower Score Indicate Better Performance For All Variables; SSRT = Stop Signal Reaction Time.

high. The number of minutes exercised in MVPa varied from 8.3 minutes to 29.6 minutes in the aerobic intervention group and from 11.9 minutes to 43.2 minutes in the cognitively engaging intervention group.

ACUTE PHYSICAL ACTIVITY VERSUS SEATED CLASSROOM LESSON

Results of the multilevel analysis assessing the effects of acute physical activity (independent of type of activity) are shown in Table III. As scores at the post-test were lower for children in the intervention groups than in the control group for some of the outcome variables (Table 2), the level of significance was set two-sided for all multilevel models, to be able to also investigate whether there is a negative effect on the interventions on the outcome variables (Glass & Stanley, 1970). The addition of study condition (acute exercise versus seated classroom lesson) did not significantly improve the covariates model for response inhibition, $\Delta\chi^2(1) = 0.08$, $p = 0.77$, lapses of attention, $\Delta\chi^2(1) = 0.97$, $p = 0.33$, mean reaction time, $\Delta\chi^2(1) = 0.46$, $p = 0.50$, and μ , $\Delta\chi^2(1) = -0.01$, $p = 0.91$. However, the addition of study condition to the model did significantly improve the covariates model for accuracy, $\Delta\chi^2(1) = 5.14$, $p = 0.02$: children in the intervention group made more errors (2.5%) than children in the control group (1.6%), $t = 2.53$, $q = 0.03$.

TABLE III
Results of the multilevel analysis for measures derived from the stop-signal task. Differences between acute exercise (independent of type) and the control condition are shown.

Fixed effects	Response inhibition			Lapses of attention			Response execution					
	SSRT (ms)			τ (ms)			Mean reaction time (ms)			Accuracy (%error)		
	B	SE	q^d	B	SE	q^d	B	SE	q^d	B	SE	q^d
Intercept	137.37	30.38	<0.01	61.31	14.27	<0.01	166.76	61.55	0.01	1.00	0.38	0.01
Sex ^a	-1.01	8.86	0.94	-3.75	6.94	0.59	-25.07	12.92	0.16	-0.03	0.35	0.94
Grade ^b	-14.61	10.89	0.18	-16.63	7.12	0.04	-34.45	12.97	0.02	-0.58	0.36	0.15
Pretest	0.46	0.11	<0.01	0.53	0.09	<0.01	0.68	0.10	<0.01	0.44	0.09	<0.01
Intervention ^c	3.86	10.37	0.71	6.87	6.98	0.65	9.04	13.04	0.71	0.90	0.36	0.03
Random effects												
Variance Classes	543.61	373.89	0.44	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00
Variance Students	1461.71	367.77	<0.01	1061.80	158.70	<0.01	3697.97	552.70	<0.01	2.747	0.411	<0.01
Deviance	921.90			867.71			978.77			337.50		
Deviance covariates model	921.98			868.68			979.22			342.64		
$\Delta\chi^2$	0.08			0.97			0.46			5.14*		
										985.02		
										985.01		
										-0.01		

Lower score indicate better performance for all variables; Significant effects related to the research questions are shown in bold; ^{a,b,c}Respectively girls, 3th grade, and control group were the reference categories; ^dp-value after FDR correction; SSRT = stop signal reaction time; *p < 0.05.

AEROBIC VERSUS COGNITIVELY ENGAGING PHYSICAL ACTIVITY

Results of the multilevel analysis assessing the effects of aerobic and cognitively engaging physical activity are shown in Table 4. Model 3 did not significantly improve the covariates model for response inhibition, $\Delta\chi^2(2) = 0.07$, $p = 0.97$, lapses of attention, $\Delta\chi^2(2) = 0.91$, $p = 0.63$, mean reaction time, $\Delta\chi^2(2) = 3.69$, $p = 0.16$, and μ , $\Delta\chi^2(2) = 3.12$, $p = 0.21$. However, the addition of study condition (aerobic exercise, cognitively engaging exercise, and the control condition) did significantly improve the covariates model for accuracy, $\Delta\chi^2(2) = 6.67$, $p = 0.04$: children in the cognitively engaging exercise group made more errors (2.9%) compared to children in the control group (1.6%), $t = 2.53$, $q = 0.04$. It is worth to note that accuracy was not normally distributed and that children in all study conditions had high accuracy levels. The difference between the cognitively engaging group and the control group was only 1.3 %. Therefore, children in the cognitively engaging group made on average 2.5 errors more based on a total of 196 trials than children in the control group.

EXPLORATIVE DOSE-RESPONSE ANALYSIS

The high inter-individual differences in number of minutes exercised in MVPA, enabled us to conduct an explorative analysis in the two intervention groups (independent of type of activity) to investigate the possibility of a dose-response relationship between MVPA and performance on the stop-signal task. Data from seven children were excluded due to more than 20% loss of heart rate data. Additionally, data from one child in the cognitively engaging intervention group was excluded, because of an outlier in number of minutes engaged in MVPA. This child exercised 43.2 minutes in MVPA, which was 2.9 standard deviations above the mean in this intervention group. A total of 34 children were included in the dose-response analysis.

The results revealed a significant improvement of the model with MVPA compared to the covariates model for the SSRT, $\Delta\chi^2(1) = 4.54$, $p = 0.03$. A significant dose-response relation between MVPA and SSRT, $t = -2.07$, $p = 0.04$ was found, indicating that more time in MVPA was related to better response inhibition (as a lower score indicates better performance). The addition of MVPA also significantly improved the model for τ , $\Delta\chi^2(1) = 4.09$, $p = 0.04$ (effect of MVPA: $t = -1.93$, $p = 0.05$; Table V and Figure 2), indicating that more time in MVPA led to reduced lapses of attention (as a lower score indicates better performance). The addition of MVPA did not signifi-

TABLE IV
Results of the Multitvel Analysis For Measures Derived From Stop Signal task. Difference Between Scrobic Physical Activity Engaging Physical Activity. And
The control condition are shown.

	Response inhibition			Lapses of attention			Response execution					
	SSRT (ms)			τ (ms)			Mean reaction time (ms)			Accuracy (%error)		
Fixed effects	B	SE	q^d	B	SE	q^d	B	SE	q^d	B	SE	q^d
Random intercept	137.20	30.56	<0.01	61.39	14.39	<0.01	166.79	60.78	0.01	1.02	0.38	<0.01
Sex ^a	-0.88	8.92	0.92	-3.72	6.99	0.60	-23.49	12.79	0.20	-0.06	0.35	0.92
Grade ^b	-14.65	10.97	0.18	-16.66	7.17	0.04	-35.12	12.81	0.02	-0.57	0.36	0.16
Pretest	0.46	0.11	<0.01	0.53	0.10	<0.01	0.68	0.09	<0.01	0.44	0.09	<0.01
Aerobic exercise intervention ^c	5.38	12.27	0.66	7.21	8.46	0.39	24.07	15.42	0.34	0.51	0.42	0.34
Cognitively engaging exercise intervention ^c	2.08	12.91	0.87	6.47	8.93	0.47	-9.00	16.42	0.87	1.14	0.45	0.04
Random effects												
Variance classes	556.63	378.40	0.42	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00
Variance students	1472.88	370.97	<0.01	1074.38	160.38	<0.01	3605.73	538.23	<0.01	2.73	0.41	<0.01
Deviance	921.91			867.77			975.53			335.98		
Deviance covariates model	921.98			868.68			979.22			342.64		
$\Delta\chi^2_{c,e}$	0.07			0.91			3.69			6.67*		
										981.89		
										985.01		
										3.12		

Lower score indicate better performance for all variables; Significant effects related to the research questions are shown in bold; ^{a,b,c}Respectively girls, 3th grade, and control group were the reference categories; ^ap-value after FDR correction; ^cSignificant improvement in model compared to covariate model indicated with *; SSRT = stop signal reaction time; Chi-squared test between aerobic exercise and cognitively engaging exercise; mean reaction time: $\chi^2(1) = 3.14$ ($q = 0.23$), accuracy $\chi^2(1) = 1.50$ ($q = 0.33$), SSRT: $\chi^2(1) = 0.06$ ($q = 0.94$), μ : $\chi^2(1) = 3.04$ ($q = 0.16$, τ : $\chi^2(1) = 0.01$ ($q = 0.94$)).

TABLE V
Exploratory Multilevel Dose-Results Of Response Analysis Between MVPA And Measures Derived From The Stop Signal Task (N=34).

	Response inhibition			Lapses of attention			Response execution					
	SSRT (ms)			τ (ms)			Mean reaction time (ms)			Accuracy (%error)		
	B	SE	q	B	SE	q	B	SE	q	B	SE	q
<i>Fixed effects</i>												
Random intercept	179.97	49.75	<0.01	122.62	27.89	<0.01	61.81	106.58	0.56	3.61	1.39	0.01
Sex ^a	-8.24	14.74	0.58	-1.75	12.17	0.89	-18.11	21.91	0.41	-0.09	0.73	0.90
Grade ^b	0.92	17.29	0.96	-12.57	11.90	0.29	-17.50	22.10	0.43	-0.15	0.72	0.83
Pretest	0.49	0.18	<0.01	0.37	0.16	0.02	0.83	0.16	<0.01	0.48	0.21	0.02
MVPA (minutes)	-3.02	1.46	0.04	-2.19	1.13	0.05	0.52	2.12	0.81	-0.12	0.07	0.07
<i>Random effects</i>												
Variance classes	167.31	440.68	0.70	0.00	0.00	1.00	0.00	0.00	1.00	0.02	0.91	0.98
Variance students	1691.35	568.41	<0.01	1139.04	275.51	<0.01	3956.04	956.88	<0.01	4.04	1.34	<0.01
Deviance	347.28			330.79			373.12			139.11		
Deviance covariates model	351.82			334.88			373.04			142.55		
$\Delta\chi^2_{\epsilon}$	4.54*			4.09*			-0.08			3.44		
										371.34		
										374.00		
										2.66		

Lower score indicate better performance for all variables; Significant effects related to the research questions are shown in bold; ^{a,b,c}Respectively girls, 3th grade, and control group were the reference categories; ^dp-value after FDR correction; SSRT = stop signal reaction time; *p < 0.05.

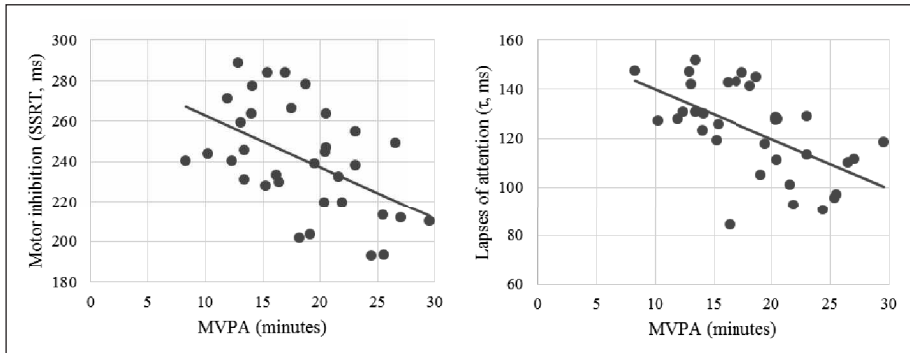


Fig. 2. The relation between the number of minutes in moderate-to-vigorous physical activity (MVPA) and response inhibition (left) and lapses of attention (right). The scores for response inhibition and lapses of attention are shown adjusted for sex, grade, pretest score, and MVPA. SSRT = stop signal reaction time. Lower score indicate better performance for response inhibition and lapses of attention.

cantly improve the covariates model for mean reaction time, accuracy, and μ , indicating no significant dose-response relation between MVPA and response execution.

Discussion

The aims of this study were to (1) investigate whether acute physical activity has positive effects on response inhibition and lapses of attention and (2) investigate whether response inhibition and lapses of attention benefit more from cognitively engaging physical activity than from aerobic physical activity. This study was the first to examine the effects of two types of acute physical activity, performed in ecologically valid environments, on response inhibition and lapses of attention in children. The main findings indicate no significant positive effects of acute physical activity, and no stronger effects of cognitively engaging physical activity as compared to aerobic physical activity. A negative effect was found for accuracy, showing that children in the cognitively engaging intervention group made more errors compared to children in the control group. Furthermore, a dose-response relation was found: more time spent in MVPA led to better response inhibition and to reduced lapses of attention in both intervention groups.

MAIN EFFECTS ON RESPONSE INHIBITION AND LAPSES OF ATTENTION

The results showed that acute physical activity did not have positive effects on response inhibition and lapses of attention. This is contradictory to previous studies conducted in laboratory settings (Chen *et al.*, 2014; Hillman *et al.*, 2009; Niemann *et al.*, 2013; Pontifex *et al.*, 2013; Tine & Butler, 2012). In these studies, the intensity of the physical activity was adapted to the children's own maximum. In ecologically valid learning environments, it is difficult to adjust the level of intensity of the activity to the children's individual level and it is difficult to control the engagement of children in group activities (Jäger *et al.*, 2015). Therefore, effects of acute physical activity that have been found in laboratory settings are difficult to translate to ecologically valid learning environments for children (Budde *et al.*, 2008; Gallotta *et al.*, 2015; Jäger *et al.*, 2014; Jäger *et al.*, 2015; Schmidt *et al.*, 2015a). This could explain why we did not find positive effects of acute physical activity, performed in ecologically valid learning environments, on response inhibition and lapses of attention.

MAIN EFFECTS ON RESPONSE EXECUTION

Acute aerobic and cognitively engaging physical activity had no effect on mean reaction time and on μ , but acute cognitively engaging physical activity led to a higher percentage of errors on go trials compared to the control condition. There was no difference between aerobic exercise and the control condition, nor between aerobic exercise and cognitively engaging exercise. This indicates that accuracy is negatively influenced by cognitively engaging exercise. However, it should be noted that accuracy was not normally distributed and the percentage of errors in the cognitively engaging exercise group was only 2.9, which is still low compared to other studies (e.g. Pliszka, Liotti, & Woldorff, 2000).

INTER-INDIVIDUAL VARIABILITY

The inter-individual variability between the children regarding internal load was high in our study. The number of minutes exercised in MVPA varied from 8.3 to 29.6 minutes in the aerobic intervention group and from 11.9 to 43.2 minutes in the cognitively engaging intervention group. Although children received identical instructions, responses to the instructions differed per child. This affects the acute physical activity-cognition relation, due to individual and

task constraints (Pesce, 2009). Task constraints such as physical and cognitive task demands described in the manual for the physical education lessons represent only a part of the constraints acting on the acute physical activity-cognition relation. Individual constraints, such as physical fitness, motor skill level, and cognitive expertise can also influence the effects of acute physical activity on cognition (Jäger et al., 2015; Pesce, 2009). In our study, individual constraints might have varied between the children, which resulted in a high variability in internal load and a mean exposure to acute physical activity too low to find group effects on lapses of attention and response inhibition.

EXPLORATIVE DOSE-RESPONSE ANALYSIS

Although there were no significant effects of acute physical activity at a group level, the explorative dose-response analysis revealed that more time in MVPA was related to better response inhibition and to reduced lapses of attention, without indications for differential effects of the type of physical activity. This finding suggests that the effects of acute physical activity are dependent on the intensity and duration, which confirms the findings in a review by Hillman, Kamijo, and Scudder (2011) and a meta-analysis by Chang et al. (2012). Hillman et al. (2011) concluded based on studies investigating effects of acute physical activity at different intensity levels (e.g. Hillman, Snook, & Jerome, 2003; Kamijo et al., 2004) that the relation between intensity and cognitive benefits may follow an inverted-U shaped function, in a way that physical activity at MVPA leads to greatest benefits on cognition. Chang et al. (2012) showed that physical activity for longer than 20 minutes results in positive effects on cognitive functions, while physical activity for only 11-20 minutes results in a negative effect on cognitive functions. Therefore, the threshold of positive effects of physical activity on cognitive functions might be around 20 minutes of MVPA. As children in the current study exercised on average 19 minutes in MVPA, this can explain why we did not find an effect at a group level, but that we found a dose-response relation.

STRENGTHS AND LIMITATIONS

A strength of this study was that two intervention types were developed, with different physical load patterns and different cognitive loads. This study contributed therefore to existing literature on the differential effects of different types of physical activity. Moreover, this study was performed in eco-

logically valid learning settings for children and could therefore easily be conducted in everyday activities.

However, there were also some limitations. The use of heart rate monitors enabled us to compare both interventions on internal load and to perform a dose-response analysis between the time in MVPA and the outcome variables. In relation to the high variability in time in MVPA, the inter-individual variability in cognitive engagement could also have been high in our study. However, we did not have a standardized instrument to measure cognitive engagement, which might have been a limitation of the current study. Schmidt *et al.* (2015b) developed a Likert scale to measure the involvement of the three executive functions (working memory, cognitive flexibility and inhibition) during physical education. However, this was not a standardized instrument. Therefore, future studies should search for objective methods to measure cognitive engagement to be able to investigate group differences and dose-response relations in cognitive engagement.

Another limitation of this study was the power. The effect size that we used for the power analysis ($d = 0.57$) was based on a meta-analysis that included two studies investigating effects of acute physical activity on interference control in laboratory settings in preadolescent children. Our study showed that it is difficult to translate the effects that are found in laboratory settings to ecologically valid learning environments for children. Therefore, the effect of 0.57 size might have been an overestimation for the effect in ecologically valid learning environments. Furthermore, the power for our second research question was low (0.50 – 0.55), as the samples in both intervention groups were small. However, we used a cluster randomized design and we included children from 24 schools in the Netherlands. The inclusion of children from different schools was a strong point of this study, as the results are more generalizable to Dutch preadolescent children than when we had taken all children from one school.

Lastly, we set our level of significance at 0.05, one-sided. However, we had to test two-sided, as the results showed that children in the intervention groups scored lower on some of the variables than children in the control group. Therefore, a power analysis with a significance level set two-sided (*a priori*) would have been more appropriate and this would have led to an increase in the number of children that had to be included for sufficient power.

Conclusion

In conclusion, we did not find positive effects of acute physical activity on response inhibition and lapses of attention in preadolescent children. How-

ever, we found evidence supporting the idea that the positive effects of acute physical activity on response inhibition and lapses of attention is related to the amount of MVPA, without indications for differential effects of the type of physical activity (e.g. aerobic versus cognitively engaging). Group-level intervention studies should take into account that individual exposure to physical activity, in terms of the amount of MVPA, is an important factor influencing the magnitude of effects on response inhibition and lapses of attention.

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