Contemporary Educational Psychology 63 (2020) 101908

Contents lists available at ScienceDirect

Contemporary Educational Psychology

journal homepage: www.elsevier.com/locate/cedpsych

Combining physical and cognitive training to improve kindergarten children's executive functions: A cluster randomized controlled trial

Mirko Schmidt[a,*], Myrto F. Mavilidi[b], Annina Singh[c], Chris Englert[d]

[a] Institute of Sport Science, University of Bern, Bremgartenstrasse 145, 3012 Bern, Switzerland
[b] Early Start, School of Education, University of Wollongong, 2522 Keiraville, Australia
[c] Department of Psychology, Zurich University of Teacher Education, Lagerstrasse 2, 8090 Zurich, Switzerland
[d] Institute of Sports Sciences, Goethe University Frankfurt, Ginnheimer Landstraße 39, 60487 Frankfurt am Main, Germany

ARTICLE INFO

Keywords:
Cognition
Physical activity
Chronic exercise
Accelerometer
Mental effort
School

ABSTRACT

Considering the convincing evidence that executive functions predict academic achievement significantly, strategies to foster executive functions in the early school years are highly requested. Besides traditional cognitive training, combined physical and cognitive interventions are intended to be a feasible way of enhancing both children's daily physical activity and executive functions. The purpose of the present study was therefore to test the effectiveness of a six-week combined physical-cognitive intervention, and to compare it to both a sedentary cognitive intervention and a waitlist control group. Using a between-subjects experimental design, 189 children aged between four and six years (M = 5.34, SD = 0.59) were recruited from 14 kindergarten classes, which were randomly assigned to one of three experimental conditions: (a) combined physical and cognitive training, (b) sedentary cognitive training or (c) waitlist control group. Before and after the interventions, all three core executive functions of updating, inhibition and shifting were measured. Physical activity was objectively measured using accelerometers during one intervention session. Linear mixed models revealed that children from both the combined physical-cognitive and the sedentary cognitive intervention improved their updating performance compared to the children of the control group. Inhibition and shifting remained unaffected by both interventions. With respect to children's daily physical activity, linear mixed models showed that only the combined physical-cognitive intervention could significantly increase the amount of step counts. The results underline the feasibility of combined physical-cognitive interventions to enhance children's daily physical activity and their cognitive performance.

1. Introduction

The ability to initialize, control and organize goal-directed behavior is essential for every human being in modern society. Three core cognitive control processes that are necessary for such goal-directed behavior are generally referred to as executive functions (EFs; Miyake et al., 2000). These include the ability to hold information in mind and process it (updating), inhibit prepotent or automatic responses and deal with interfering distractors (inhibition), and to change perspectives or react and adapt to changing tasks and demands of the environment (shifting). EFs have been shown to predict school readiness in young children (Blair & Diamond, 2008; Roebers et al., 2014), and are consistently reported to robustly predict academic achievement to a large extent (Bull, Espy, & Wiebe, 2008; Schmidt et al., 2017; Viterbori, Usai, Traverso, & de Franchis, 2015). Additionally, they have also been found to be negatively associated with a wide range of school-related behavioral problems (Blair & Diamond, 2008; Espy, Sheffield, Wiebe, Clark, & Moehr, 2011; Friedman et al., 2007). Considering the relevance of EFs for children's daily behavior and performance at school, the question of how these cognitive processes can be enhanced arises.

1.1. Direct and indirect cognitive trainings to improve EFs

Various types of interventions have been proposed to foster EFs in children (Diamond & Lee, 2011), including computer-based trainings, educational programs and physical activities (Diamond, 2015; Karbach & Unger, 2014; Mackey, Hill, Stone, & Bunge, 2011; Tomporowski & Pesce, 2019). Despite the ongoing debate on the effectiveness and the transfer of training effects (Kassai, Futo, Demetrovics, & Takacs, 2019; Melby-Lervag & Hulme, 2013; Morrison & Chein, 2011), there seems to

* Corresponding author.
E-mail addresses: mirko.schmidt@ispw.unibe.ch (M. Schmidt), myrto.mavilidi@uow.edu.au (M.F. Mavilidi), annina.singh@phzh.ch (A. Singh), englert@sport.uni-frankfurt.de (C. Englert).

https://doi.org/10.1016/j.cedpsych.2020.101908

Available online 11 August 2020

be convincing evidence that EFs can be enhanced if interventions are designed to be constantly challenging, playful, and enjoyable (Diamond & Ling, 2016; Takacs & Kassai, 2019). Many school-based interventions, which can be classified into direct or indirect trainings, have been developed and evaluated in recent years (Otero, Barker, & Naglieri, 2014; Scionti, Cavallero, Zogmaister, & Marzocchi, 2020).

On the one hand, direct trainings are typically conceptualized to target one single EF, for instance computerized working memory training (Klingberg, Forssberg, & Westerberg, 2002), which specifically stimulates working memory. For example, in a sample of 101 four year old children, Bergman Nutley et al. (2011) tested the effects of a computerized working memory training (15 min/day for 25 days) on different working memory and problem solving measures. They found improvements on several trained and non-trained working memory tests, but not on problem solving tests. By way of example, this study shows that direct trainings are generally capable to evoke larger improvements within the specific domain, but mostly fail in producing far transfer effects (see also Melby-Lervag & Hulme, 2013).

On the other hand, indirect trainings are mostly designed to target multiple EFs through a broader range of activities that can be easily embedded in the preschool curriculum, such as, for example, *Tools of the Mind* (Bodrova & Leong, 2007); a one-two-year intervention based on 40 EF-promoting activities. Assigning children from low-income families to either a “Tools” group or an active control group covering the same academic content without addressing EFs, Diamond, Barnett, Thomas, and Munro (2007) found that children receiving “Tools” outperformed their counterparts of the control group, especially in the most demanding EF tasks. Even though indirect interventions mostly lead to smaller effect sizes than direct trainings, they seem to be capable of producing substantial transfer effects (Diamond & Ling, 2016). In addition, a recent meta-analysis has shown that indirect trainings which target core EFs implicitly, for example by means of constantly challenging and playful games, are “similarly or more effective, and these activities are more enjoyable and can be more easily embedded in children’s everyday activities” (Takacs & Kassai, 2019, p. 1).

In recent years, researchers have developed interventions that combine the advantages from both direct and indirect trainings. To enhance the effectiveness and the ecological validity for the school setting, these interventions are generally characterized by activities that are designed to target specific core EFs (as in direct trainings), but by applying a game-centered and group-based approach (as in indirect trainings). For example, Röthlisberger, Neuenschwander, Cimeli, Michel, and Roebers (2011) evaluated the effects of an intervention specifically targeting the three core EFs in preschool and early primary school children (6-year-old). After completing their program, which consisted of cognitively challenging games over a duration of six weeks, typically developing children in the intervention group improved their interference control regarding their response accuracy to a stronger degree than the children in the control group. Using the same intervention material, but adapting the difficulty level to suit the age group of 10–12-year old school children, Benzing et al. (2018) found larger improvements in updating and shifting performance of children in the experimental group, compared to the waiting control. For this, an intervention was used which trained their EFs by means of group-based card and board games, completed twice a week for 30 min each.

Another longitudinal study evaluating the effects of a chronic training intervention in 5-year-old children reported similar results (Traverso, Viterbori, & Usai, 2015), where they employed a comparable game-based intervention using low-cost material, consisting of 12 sessions over the period of one month. Results revealed an improvement in all three core EFs in children of the training group, compared to children in the control group. When the same intervention was administered by regular teachers instead of a trained psychologist (to verify its ecological validity), only the inhibition scores improved over time (Traverso, Viterbori, & Usai, 2019). All these studies, however, compared their intervention to a control group without specific treatment.

1.2. Physical activity to improve EFs

As indicated by the conclusions drawn in several systematic reviews and meta-analyses (Álvarez-Bueno et al., 2017; De Greeff et al., 2016; Hillman & Biggan, 2017), physical activity is a promising approach to improve children’s EFs, whereby in exercise and cognition research there is a clear distinction between the effects of *acute* and *chronic* physical activity on cognitive functioning (Best, 2010). Whereas acute physical activity denotes single bouts of physical activity provoking instant changes in cognitive functioning, chronic physical activity includes multiple sessions or habitual physical activity, provoking cognitive changes evident in the long term (Pesce, 2012). Depending on the disciplinarity as well as the temporal perspective, the effects of physical activity on cognition are explained by different underlying mechanisms (Mavilidi et al., 2018).

From a physiological perspective, multiple mechanisms are proposed to contribute to the effects of *acute* physical activity on cognition (Pontifex et al., 2019). Research using acute bouts of physical activity have shown modulated event-related potentials (Hillman, Kamijo, & Scudder, 2011; Khan & Hillman, 2014) and an increased functional connectivity of brain networks (Weng et al., 2017). These neurophysiological changes are, in turn, thought to lead to altered psychological states, such as increased arousal, making a larger pool of attentional resources available and therefore facilitating performance in subsequent cognitively effortful tasks (Audiffren, Tomporowski, & Zagrodnik, 2009). From a psychological perspective, there is another explanation for cognitive improvements induced by acute and chronic physical activity, elaborated by the cognitive stimulation hypothesis.

The assumption of the cognitive stimulation hypothesis is that non-automated and cognitively challenging physical activity activates the same brain regions that are used to control higher-order cognitive processes (Best, 2010; Pesce, 2012; Tomporowski, McCullick, Pendleton, & Pesce, 2015). Thus, enhanced cognitive performance after a single bout of (*acute*) physical activity is explained by a specific pre-activation of those exact cognitive processes, which are then used in a subsequent cognitive task (Budde et al., 2008). For the effects of *chronic* physical activity, it is assumed that the repeated addressing of EF processes through designed physical activities leads to a long-term change of only those EFs, which are specifically addressed by the training (Herold, Hamacher, Schega, & Müller, 2018). This conceptualization of transfer as a limited phenomenon is not novel, going back to Thorndike and Woodworth (1901). Its revival was brought about and developed further in modern transfer theories, such as the primitive elements theory of cognitive skills (Taatgen, 2013). According to these theories, and considering meta-analytical evidence showing only near-, but not far-transfer effects among children’s EFs (Kassai et al., 2019), physical activities should be designed in a way that triggers the same EFs that one intends to improve. This supposition of shared cognitive processes is based on both theoretical and neuroimaging literature.

In theoretical frameworks, overlapping conceptualizations of motor and cognitive control become apparent: In the cognitive literature, cognitive control, executive control or executive functioning describes cognitive processes involving monitoring, planning, sequencing and adapting ongoing operations (Best & Miller, 2010; Miyake et al., 2000). In the literature on motor behavior and development, the term motor control is used to describe motor planning, organizing, monitoring, motor-coordinative adjustment as well as cross-modal integration, rather than motor power or motor speed. Similar to the cognitive domain, motor control is needed under high demands of speed and accuracy (Schmidt & Lee, 2011). From these definitions it is obvious that motor control involves EFs (Diamond, 2000; Roebers & Kauer, 2009), for example, updating of task requirements enabling forward planning in a dance choreography, inhibition of frequently used movements (prepotent responses) in anti-imitation games, or shifting the focus of attention in sports with fast changing situations (Tomporowski et al., 2015).

More direct evidence for this theoretical assumption of shared information processes in both motor and cognitive control stems from neuroscience literature. Neuroimaging studies indicate that for the mastery of executive function tasks (involving executive control of attention and working memory) and motor-coordinative tasks (emphasizing speed and accuracy of motor responses), the prefrontal cortex and the cerebellum are primarily activated (Diamond, 2000; Serrien, Ivry, & Swinnen, 2007). In sum, EFs are involved not only in mastery of complex cognitive tasks, but also in certain motor tasks.

1.3. Empirical evidence on the effects of acute and chronic physical activity

Against this theoretical and neuroscientific overlap between action and cognition, researchers have started to recognize the importance of qualitative characteristics when specifically designing physical activity interventions to improve EFs (Pesce & Ben-Soussan, 2016; Pesce, 2012). Considering, for example, the idea that various physical activities may not only differ in their intensity, duration, and frequency, but also, for example, in their cognitive challenges, necessitating EFs to master them (Vazou, Pesce, Lakes, & Smiley-Oyen, 2019). Although a recent review suggested that interventions integrating cognitive and motor components may offer enhanced cognitive and learning benefits in children (Mavilidi et al., 2018), findings from *acute* studies explicitly testing the cognitive stimulation hypothesis remain equivocal (Paschen, Lehmann, Kehne, & Baumeister, 2019). Some studies have revealed positive effects on cognitive performance in favor of the cognitively challenging condition (Benzing, Heinks, Eggenberger, & Schmidt, 2016; Budde et al., 2008; Jäger, Schmidt, Conzelmann, & Roebers, 2014; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009; Schmidt, Benzing, & Kamer, 2016), some have found no difference (Best, 2012; Jäger, Schmidt, Conzelmann, & Roebers, 2015), and others have even reported detrimental effects compared to physical activity without cognitive challenges (Egger, Conzelmann, & Schmidt, 2018; Gallotta et al., 2012, 2015).

When it comes to *chronic* physical activity interventions, there is tentative evidence that cognitively engaging aerobic exercise requiring strategic behaviors, complex motor coordination and adaptation to changing tasks benefit children's EFs more than non-engaging simple and repetitive activities (Chang, Tsai, Chen, & Hung, 2013; Egger, Benzing, Conzelmann, & Schmidt, 2019; Koutsandreou, Wegner, Niemann, & Budde, 2016; Pesce et al., 2016; Schmidt, Jäger, Egger, Roebers, & Conzelmann, 2015; Van der Niet et al., 2016). For example, in primary school children aged between 10 and 12 years, Schmidt et al. (2015) compared a pure aerobic exercise intervention in physical education, a team game intervention combining both physical and cognitive demands, and an active control group. Positive effects were found for children's shifting performance when using high cognitive engagement within a physical activity, compared to pure aerobic activities with low cognitive engagement. This underscores the importance of cognitive demands within applied physical activities to boost EFs in older children. However, the study did not include a pure cognitive intervention, which in turn only allows the conclusion that combining physical activity with cognitive challenges is more effective in promoting EFs than a pure aerobic exercise intervention.

To overcome this shortcoming and to replicate these findings in younger children aged between 7 and 9 years, Egger et al. (2019) conducted a 20-week classroom-based physical activity program, with either high physical exertion and high cognitive engagement (*combo group*), high physical exertion and low cognitive engagement (*aerobic group*), or low physical exertion and high cognitive engagement (*cognition group*). Results showed that only the combo group displayed enhanced shifting performance. The authors, however, also reported that the implementation fidelity decreased after the first 10 weeks, with teachers testifying the challenges of such long-lasting interventions. Thus, the question arises of whether the same effects of cognitively challenging chronic physical activity can be achieved in kindergarten children using a shorter and thus more feasible intervention. Despite the explicit call for more research, in which the "right" control group is carefully chosen (Singh et al., 2019), studies of combined interventions using both cognitive and physical demands in kindergarten children are still lacking in research.

1.4. The current study

In the current study, therefore, we wanted to examine the influence of a combined physical-cognitive intervention on the three core EFs in kindergarten children. Since both direct cognitive trainings and physical activity programs are considered advantageous in promoting EFs in young children (Diamond & Ling, 2016), in the present study, we expected a stronger positive effect of our indirect training when adding physical activity on top of the cognitive intervention. Given the overlapping processes inherent in motor performance and EFs (Oberer, Gashaj, & Roebers, 2018; Roebers et al., 2014; Schmidt et al., 2017), and that previous research has found positive effects of a combined intervention with both cognitive engagement and physical activity compared to pure aerobic exercise in primary school children (Egger et al., 2019; Schmidt et al., 2015), we hypothesize that a combined physical-cognitive intervention will benefit kindergarten children's EFs more than a sedentary cognitive training and an active control condition. To test these hypotheses, an intervention with both cognitively demanding and physically engaging games (gross motor activities) was developed and compared against an intervention with equal amounts of cognitive challenge but limited physically engaging games (fine motor activities), both carried out in kindergarten classes over a period of six weeks. Since the most recent meta-analyses investigating both the effects of chronic physical activity (Xue, Yang, & Huang, 2019) and cognitive training interventions (Kassai et al., 2019) on EFs among children and adolescents did not detect the duration as a significant moderator, we had to derive the optimal duration from those studies that examined the most similar interventions. Whereas the reviewed indirect cognitive trainings with positive effects on children's EFs lasted between four (Traverso et al., 2015, 2019) and six weeks (Benzing et al., 2018; Röthlisberger et al., 2011), the trainings with cognitively challenging physical activities lasted between six weeks (Schmidt et al., 2015) and six months (Pesce et al., 2016), with decreased implementation fidelity after 10 weeks of intervention time (Egger et al., 2019). Thus, to compare our results with those of previous studies and to ensure high implementation fidelity (Carroll et al., 2007), a time period of six weeks was chosen. A waiting control group with ongoing curricular classes was used as a control condition.

2. Method

2.1. Overview

Two 6-week interventions with diverging levels of physical activity were conducted in the classroom and compared to a waiting control group with respect to their effects on kindergarten children's EFs. Classes in the physical-cognitive condition carried out a gross motor game program with both high physical and cognitive demands. Classes in the cognitive condition went through a similar fine motor game program with low physical, but high cognitive demands. Classes in the waiting control group followed the regular school curriculum and received all intervention contents following posttest. Altogether, 14 classes were randomly assigned to one of these three experimental conditions. The teachers were informed about the basic aims of the study but were blinded with respect to the specific study hypotheses.

All kindergarten classes were recruited in the cantons of Bern, Lucerne and Zurich (Switzerland). The Institutional Review Board of the Faculty of Human Sciences at the University of Bern approved ethical consent for the study protocol, which adhered to the latest version of the declaration of Helsinki. The parents/legal guardians of all participating children signed an informed consent form. All children were explicitly asked before the first data collection session whether they wanted to participate, and informed that they could discontinue at any time during the study. All data were treated confidentially.

2.2. Participants

In total, 189 children (91 female) aged between four and six years ($M = 5.34$, $SD = 0.59$) participated in the present study. Detailed sample characteristics are shown in Table 1. There was some loss of data due to sick leave, technical problems, or refusal of participation. The percentage of pupils with incomplete values ranged between 1.1% for the inhibition task and 6.9% for the updating task. Since Little's Missing Completely at Random test (Little & Rubin, 2002) identified no systematic pattern in the missing data, χ^2 (149) = 241.35, $p > .999$, the missing values were imputed using the expectation–maximization (EM) algorithm. Separate ANOVAs showed that there were no significant differences between the three experimental conditions with respect to age, $F(2, 186) = 0.60$, $p = .549$, $\eta_p^2 = 0.006$, weight, $F(2, 186) = 1.63$, $p = .199$, $\eta_p^2 = 0.017$, height, $F(2, 186) = 0.69$, $p = .505$, $\eta_p^2 = 0.007$, and BMI, $F(2, 186) = 1.03$, $p = .358$, $\eta_p^2 = 0.011$. A chi-square test indicated that the gender distribution did not differ between the three groups, $\chi^2(2) = 5.34$, $p = .068$, Cramer's $V = 0.169$.

Considering a previous study that tested the effects of a chronic physical-cognitive intervention on all three core EFs with participants of a comparable age (Egger et al., 2019), an a priori power analysis using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) was performed with power (1 – beta error probability) = 0.80, alpha error probability = 0.05, effect size $f = 0.25$, numerator $df = 3$, number of groups = 3, and number of covariates = 1, resulting in an optimal sample size of 179.

2.3. Materials and procedure

The two interventions were carried out by the regular school teachers in their classroom, during the morning classes between 9 am and 12 pm. Prior to the study, teachers completed a half-day training program instructing them in the basic principles, aims and purposes of the intervention program, demonstrating the specific contents with the special teaching materials. Over a period of six weeks, four 15 min sessions per week were carried out in the group setting, whereby the entire intervention was intended to cover 24 sessions. To test implementation compliance (Dane & Schneider, 1998), teachers had to report the number of sessions carried out effectively. With a range between 20 and 24, they reported to have implemented $M = 23.20$ ($SD = 0.84$) sessions in the physical-cognitive group and $M = 21.80$ ($SD = 1.10$) sessions in the cognitive group, indicating high compliance with the training.

At pretest, children's weight and height were measured while children's age and gender were received from the teachers. As primary outcome variables, updating, inhibition, and shifting were assessed individually with the help of three standardized cognitive tests adapted for computer use. The testing took place in in a quiet room at both pretest and posttest by two investigators, who were blinded with respect to the conditions. They gave general instructions whilst the children were encouraged to work quietly but to ask questions about the test whenever something was unclear. The sequence of the conducted tasks within cognitive assessment was counterbalanced within classes and the complete testing lasted about 15 min per child. Following posttest, children of all participating classes also received a small lizard toy in return for their participation.

2.4. Experimental conditions

Children were instructed to participate in twelve games (see Tables 2 and 3) with increasing difficulty, specifically designed to target EFs (Egger et al., 2018, 2019).[1] There were four games to be played each week. After three weeks, all games were repeated, since practice is required to build up automatic motor and cognitive processes that can be inhibited or changed. The games were based on experimental tasks used in the previous literature that quantify the individual differences in EFs (Carlson, 2005) and on action games specifically designed to foster children's EFs (Tomporowski, McCullick, & Pesce, 2015). For example, an adapted version of the well-known imitation game Simon Says (Strommen, 1973) was used to address children's inhibition, built upon a Go/No-Go paradigm requiring the playing child to respond to target stimuli but inhibit from responding to non-target stimuli. However, considering the task-impurity problem (Miyake & Friedman, 2012) indicating that EFs interact with each other, each game was intended to tap multiple EFs.

To increase the chance of reaching children's optimal challenge point (Pesce et al., 2013), each game was designed with three incremental levels of difficulty. In the first 3 weeks, the games were introduced by the teacher and played at a lower difficulty level. From the fourth week on, depending on the teacher's judgment of the children's understanding, the difficulty level was raised to adapt to the children's skills. And by doing this, to constantly maintain high cognitive demands. The level of difficulty was increased by a) adding more items to be remembered and/or manipulated in short-term storage (updating), introducing new rules, which necessitate responding in a way that conflicts with an older rule or a dominant behavior (inhibition), and b) including multiple rule sets to fluently switch between (shifting). All games were child-friendly and suitable for kindergarten classrooms. To enhance children's motivation and make them more age-appropriate, the games were adapted to the frame story of Edi the lizard.

Physical-cognitive condition. The physical-cognitive training program consisted of twelve games targeting the three core EFs; updating, inhibition, and shifting, whereas the main focus was distributed equally over the duration of the intervention (Table 2). The games were conceptualized to require gross motor movements, which in turn should increase physical activity. For example, in week 6, the imitation game Lizard Edi says (adapted from Strommen, 1973) was played. On the first level, children had to perform various gross motor movements (e.g. jumping up, turning quickly in circles), but only when the command of the teacher was prefaced with "Lizard Edi says". Otherwise, the children had to stand still. Then, on the next difficulty level, the task was changed in so far, that the children had to carry out the "opposite" of the commanded movement (e.g. instead of turning quickly, turning slow in circles). At the highest level, the commanded movements were only given to a predefined group of children (e.g. only the girls). The children had to update the new information, quickly find solutions for the "opposite" movement and inhibit the movements depending on the verbal command.

Cognitive condition. The cognitive training program consisted of the same or similar twelve games, also targeting the three core EFs (Table 3). In contrast to the physical-cognitive training, the games required low physical activity, since they were based on fine motor movements and cognitive demands. However, there were also four games to play each week. As in the physical-cognitive training, all the games were included in the lizard frame story and the level of difficulty was raised constantly after the first three weeks. Also in week 6, the game Lizard Edi says (adapted from Strommen, 1973) was played in the cognitive condition. While sitting on a chair, the children had to perform various fine motor movement (e.g. closing the fist, clapping the

[1] For replication or dissemination, all the teaching materials and audio files can be obtained from the corresponding author.

Table 1
Means (and standard deviations) for the background, the manipulation check and the dependent variables in the three experimental conditions.

	Physical-cognitive Group (n = 75)	Cognitive Group (n = 52)	Control Group (n = 62)
Sample characteristics			
Age (years)	5.39 (0.58)	5.35 (0.62)	5.28 (0.58)
Gender distribution (male/female)	34/41	34/18	30/32
Weight (kg)	20.86 (3.62)	20.26 (3.20)	19.87 (2.74)
Height (m)	1.15 (0.06)	1.14 (0.06)	1.14 (0.06)
BMI (kg·m^{-2})	15.66 (1.98)	15.40 (1.56)	15.25 (1.38)
Manipulation check variable			
Steps per minute	47.75 (15.64)	12.69 (9.25)	15.06 (14.21)
Enjoyment	3.83 (0.52)	3.81 (0.56)	.
Dependent variables			
Pretest Updating (accuracy)[a]	15.41 (4.48)	14.25 (6.35)	16.15 (5.24)
Pretest Inhibition (accuracy)[a]	0.76 (0.20)	0.78 (0.23)	0.76 (0.24)
Pretest Inhibition (RT)[b]	2059 (1047)	2503 (1251)	1913 (972)
Pretest Shifting (accuracy)[a]	12.12 (7.12)	12.48 (6.04)	13.90 (6.51)
Posttest Updating (accuracy)[a]	17.49 (4.33)	17.33 (5.92)	16.36 (4.78)
Posttest Inhibition (accuracy)[a]	0.84 (0.16)	0.83 (0.20)	0.83 (0.14)
Posttest Inhibition (RT)[b]	1649 (554)	2131 (950)	1529 (525)
Posttest Shifting (accuracy)[a]	14.63 (5.77)	14.77 (5.99)	15.37 (5.89)

Note. BMI = body mass index, RT = reaction time. [a]Accuracy corresponds to the number of correct responses. [b]Reaction time is given in milliseconds.

hand), but only when the command of the teacher preceded with "Lizard Edi says". Otherwise the children had to sit still without moving their hands. On the second level, children were asked to carry out the "opposite" of the commanded fine motor movement (e.g. instead of closing the fist, spreading the fingers). On the highest level, a rule was added in which the commanded movements were only given to a defined group of children (e.g. only the girls).

Control condition. The control condition consisted of an active waiting-list group. Teachers of this condition were asked to continue to teach according to the curricular requirements and were informed that they will receive the resources of both trainings after the posttest.

2.5. Manipulation check variables

To compare the three experimental conditions regarding their physical activity, the LightMove 3 activity sensor, a lightweight (26 g) and small (62.3 × 38.6 × 11.5 mm) monitor, was used (movisens GmbH, Karlsruhe, Germany). The LightMove 3 is a three-axial acceleration sensor with a measurement range of ± 8 g and a sampling rate of 64 Hz. Despite its capability to additionally measure barometric pressure, temperature, and ambient light sensor, only physical activity parameters were processed in the present study. Reliability and validity of the device has been proven by Anastasopoulou et al. (2014), using indirect calorimetry as reference measure for activity energy expenditure. The assessment of objective physical activity took place on one morning within the period of one intervention session. In order to ensure a high generalizability of the results, the data collection was distributed over the entire intervention phase. As recommended by Johansson, Larisch, Marcus, and Hagströmer (2016), the acceleration sensor was attached to the child's wrist and objectively measured steps based on body acceleration data were derived. Daily step counts were reported to be valid for physical activity levels in preschoolers (Pagels, Boldemann, & Raustorp, 2011) and step counts based on accelerometers were found to be reliable to measure physical activity in preschool children (De Craemer et al., 2015). Hence, steps per minute during the time of the intervention game were used as the manipulation check variable. In the control condition, a matched time window was randomly chosen from the available data.

To test if the children receiving the physical-cognitive and the cognitive training enjoyed the intervention to the same extent, their enjoyment was measured using a single-item question: "How much did you enjoy the games with Edi the lizard?". The questions had to be answered by pointing on a pictorial thumbs up 4-point Likert scale. Even though this scale has not been validated, using thumbs up pictures appeared to lead to comparable results as using smileys (Toepoel, Vermeeren, & Metin, 2019).

2.6. Cognitive assessment

To measure EFs, three standardized cognitive tests were used and adapted for computer use with identical instructions and stimulus material using OpenSesame (Mathôt, Schreij, & Theeuwes, 2012). The sequence of the conducted tasks within the cognitive assessment was counterbalanced and lasted about 15 min per child.

Updating was measured with the computerized pictorial updating task, which is an adapted n-back task (Jäger et al., 2014; Lee, Ng, Bull, Pe, & Ho, 2011). A series of animals were subsequently shown on the computer screen for one second each, and the children were instructed to memorize the last three animals they saw. However, the children were not informed beforehand how many animals they would see, meaning that they had to update their memory constantly. After four practice trials, the children worked on eight trials in a randomized order, and in each trial, they were asked to name the last three animals they had seen before the experimenter interrupted them. The total number of correct answers was used as the dependent measure. Evidence for the acceptable reliability and construct validity of the pictorial n-back task has been proven, with an internal consistency score of Cronbach's alpha = 0.87 in a sample of 6 year old children (Lee et al., 2012) and with correlations of r = 0.41 between the n-back and the listening recall memory task in a sample of 151 elementary school children (Lee et al., 2011).

Inhibition was measured with the Stroop-like day-night task for children that lasted three minutes (Gerstadt, Hong, & Diamond, 1994). This task was found to be reliable in EEG measures (Wolfe & Bell, 2004), and to be sensitive in preschool ages (Diamond & Taylor, 1996). In this task, either a picture of a moon or sun was presented centrally on the screen. The task required the children to answer with "day" when presented a moon-card, and to answer with "night" when shown a sun-card. Participants were told to answer as fast and as correct as possible. Following four practice trials to check the correct understanding of the instruction, all children were presented 16 cards at a given, pseudorandom order. Both the child's response accuracy and the reaction time were recorded. The first verbal response was rated on the log sheet, whereas the reaction time was assessed by pressing the spacebar of the laptop used for the cognitive testing. Following Gerstadt et al. (1994), individual percentage of correct responses and reaction time were used

Table 2
Summary of the twelve games in the physical-cognitive condition in carried out order.

Game	Description	EF involvement
One Lizard, two lizards	Children need to stop an ongoing movement (e.g. hopping, turning, dancing) in a specific way (e.g. sit down quickly, freeze, stand on one leg) when the song is paused unexpectedly. The specific position to stop is given by a verbal or visual command. To increase the level of difficulty, the children are only allowed to perform a commanded stopping position that is different to the previous position. Children are challenged to find and immediately execute a creative new stopping position.	Inhibit prepotent motor reactions, adapt to rule changes, remember different rules and motor actions, update the last stopping position, find new solutions for a different stopping position
Billy Billy Buh	Children perform a predefined movement (i.e. response, such as a crouch or jump), whenever they hear the verbal signal 'Billy Billy Buh' (i.e. stimulus). After some practice stimulus–response bindings are exchanged, and an additional rule is added where children have to inhibit the movement when the verbal signal 'Buh' is omitted ('Billy Billy').	Remember different motor actions, coordinate a motor reaction with a verbal command, inhibit prepotent responses, adapt to rule changes
Lizard song	Adjust different gross motor movements (e.g. crawling, kicking) in response to changing music tempo. As an additional rule, children inhibit the movement when the music is paused unexpectedly.	Adjust to the rhythm of the music, inhibit prepotent motor responses, adapt to rule changes
Wild farm	Children are moving around in the classroom and imitate an assigned animal (movement and/or noise). The task is to find the corresponding animal within the other children. Animal roles and conditions (movements and/or noises) are exchanged every round.	Deal with interfering distractors (animal noises and movements from others), inhibit prepotent motor and acoustic response
Parking meter	Children run around the classroom while listening to a song. Whenever they hear a predefined word (i.e. stimulus), they interrupt their running and immediately perform an assigned gross motor movement (i.e. response), such as a crouch or jump. After some practice to learn these stimulus–response bindings, they are exchanged.	Remember stimulus–response bindings, connect and re-connect a specific motor response with a verbal stimulus, adapt to rule changes, inhibit prepotent motor responses
The strict farmer	Execute predefined motor tasks (e.g. turning around, jumping jack) according to a verbal command and depending on predefined animal roles. After some practice, a visual stimulus (green and red card) is added, meaning one should only perform the commanded movement when the green card is shown. After some time, assignment of the animal role is exchanged.	Remember an ascribed animal role, inhibit prepotent motor responses, adapt to rule changes
Story with movements	Recall an assigned animal role and perform a predefined fast movement pattern (i.e. a response, such as jump on a chair and climb down) in response to some predefined terms (i.e. stimulus) in a story. After some practice to learn these stimulus–response bindings, they are exchanged.	Remember an ascribed animal role, connect and re-connect a specific motor response with a verbal stimulus, adapt to rule changes
Lizard dance	Children imitate a movement shown on a card (e.g. jumping jack, bounce back and forth), but only if the card shown before was different. Children are challenged to quickly execute a different movement. After some practice, a visual stimulus (lizard on the movement card) is added, where one is required to perform a certain predefined gross motor movement which is not shown on the card.	Remember the sequence of cards and motor actions, inhibit prepotent motor responses, connect and re-connect a specific motor response with a visual stimulus, adapt to rule changes
On the wall	Whenever a predefined lyric (i.e. stimulus) is sung in the song, children interrupt fast walking and perform a certain gross motor movement (i.e. a response, such as frog hop, lie down or get up quickly). The action should be inhibited when the specific lyric is skipped in the song.	Connect a specific motor reaction with a verbal command, remember different motor actions, inhibit prepotent motor reactions
Fruit and vegetable dance	Children are sitting in a circle and get assigned a fruit or vegetable role. In response to a verbal command (e.g. "all bananas", "all apples"), children change seats quickly. After practice, further verbal commands are added and roles are exchanged.	Remember an ascribed role, react quickly to a verbal command, adapt to rule changes
Lizard Edi says	Perform the commanded gross motor movement (e.g. turn quickly in circles), but only when the command is prefaced with "Lizard Edi says…". After some practice, the children carry out the "opposite" of the commanded movement (e.g. instead of turning quickly, turning slow in circles). After some practice, the commanded movements are only given to a group of children (e.g. only the girls).	Connect a specific motor reaction with a verbal command, inhibit prepotent motor reactions, adapt to rule changes, find solution for the "opposite" movement
Grass, Grasshopper	Execute a predefined gross motor action (i.e. a response, such as fast frog hops or a two-legged jump), when a specific song passage (i.e. stimulus) is played. After some practice to learn these stimulus–response bindings, they are exchanged.	Remember different motor actions, connect and re-connect a motor reaction with a verbal command, adapt to rule changes

as dependent variables for inhibitory control. Evidence for the acceptable reliability and construct validity of the Stroop-like day-night task has been proven, with test–retest reliability of $r = 0.84$ in a sample of 4–5 year old children tested two weeks apart (Thorell & Wåhlstedt, 2006) and with correlations of $r = 0.44$ between the Stroop-like day-night and the grass-snow task in a sample of 107 preschool children (Carlson & Moses, 2001).

Shifting was measured with the Dimensional Change Card Sort (DCCS; Zelazo, 2006). In the pre-switch phase, the children were asked to sort a series of bivalent test cards (e.g., blue boats, red rabbits) according to their color (e.g., all blue cards had to be sorted on one stack and all red cards on another stack) or their shape (e.g., all cards depicting a rabbit had to be sorted on one stack and all cards depicting boats on another stack; order counterbalanced). In the post-switch phase, the instructions changed as the children had to sort the same types of cards according to the respective other dimension (i.e. if they had to sort the cards according to their color in the pre-switch phase, they now had to sort the cards according to their shape in the post-switch phase). Each phase started with two practice trials and was followed by six trials. The rules were repeated on each trial. After the post-switch phase, children proceeded to the border version containing the same target cards as the previous two phases, plus so-called border test cards which were identical to the other target cards with the only difference being that they had a black border around them. The

Table 3
Summary of the twelve games in the cognitive condition in carried out order.

Game	Description	EF involvement
The cheeky lizard child	Children are sitting on chairs in a circle. One child is hiding an object behind his back, while the others are pretending to hide it as well. The goal is to avoid eye contact and control facial expression, so that the seeker can't find the object. To increase the level of difficulty, rule changes are added (e.g. increase number of objects, pass the object behind the back).	Inhibit revealing emotions, adapt to rule changes, remember different rules
Poor black cat	Children are sitting on chairs and refrain from laughing while a child meows like a cat and pulls a funny face. Different rule changes are added (e.g. speak a predefined sentence without laughing, increased distraction by other children).	Remember predefined sentences, inhibit emotions, find distraction strategy, adapt to rule changes
Lizard song	Adjust different fine motor movements (e.g. fidget with fingers, fists rotating in a circle) in response to changing music tempo. As an additional rule, children inhibit the movement when the music is paused unexpectedly.	Remember different fine motor actions, adjust to the rhythm of the music, inhibit prepotent fine motor responses, adapt to rule change
Listen up!	While sitting on chairs, half of the group imitate animal noises shown on cards, whilst the other group's task is to find the corresponding animal only by hearing the imitated noises. Roles and animal cards are exchanged every round. As an additional rule, children inhibit the animal noises when a lizard is shown on the card.	Remember different animals and rules, inhibit prepotent acoustic response, adapt to rule changes
Parking meter	Children are sitting on chairs and execute an enduring fine motor action (e.g. riding a steering wheel with hands) while listening to a song. Whenever they hear a predefined word (i.e. stimulus), they interrupt their action and immediately perform a certain fine motor movement (i.e. response), such as drawing a circle in the air with fingers. After some practice to learn these stimulus–response bindings, they are exchanged.	Remember different fine motor actions, inhibit prepotent fine motor responses, connect and re-connect a specific fine motor response with a verbal stimulus, adapt to rule changes
Secret language	While sitting on chairs, children execute a sequence of hand motions (e.g. clap, fingers snip) after a visual command. The length and difficulty of the sequence increases every round.	Remember sequences of hand motions, inhibit prepotent fine motor responses
Story with movements	Recall an assigned animal role and perform a predefined movement pattern (i.e. a response, such as clap your hands), in response to used terms (i.e. stimulus) in a story. After some practice to learn these stimulus–response bindings, they are exchanged.	Remember an assigned animal role, connect and re-connect a specific fine motor response with a verbal stimulus, adapt to rule changes
Fruit salad	Fruits and vegetable cards are shown to the children while they're sitting on chairs. The task is to name the fruit/vegetable shown on the card, but only if the card shown before it was different. Children are challenged to name a different fruit. After some practice, a visual stimulus (lizard on the fruit/vegetable-card) is added, meaning they need to say a certain predefined word instead of the fruit/vegetable shown on the card.	Remember sequences of cards, inhibit prepotent responses, connect and re-connect a specific response with a visual stimulus, adapt to rule changes
On the wall	While sitting on a chair, perform a predefined fine motor action (i.e. a response, such as clap your hands or put hands on top of each other), whenever a specific lyric (i.e. stimulus) is sung in the song. The action should be inhibited, when the specific lyric is skipped in the song.	Connect a specific fine motor reaction with a verbal command, remember different fine motor actions, inhibit prepotent motor reactions
Kim's game with animal card	Children are sitting in a circle while memorizing different animals on cards. After, they try to find the missing animal card that was taken out, recalling the correct name. As an additional rule, it is only allowed to imitate the animal noise instead of naming it. Animal cards are exchanged every round.	Remember cards, inhibit prepotent responses, adapt to rule changes
Lizard Edi says	Perform the commanded fine motor movement (e.g. close fist), but only when the command is prefaced with "Lizard Edi says…". After some practice, the children carry out the "opposite" of the commanded movement (e.g. instead of close fist, spread fingers). After practice, the commanded movements are only given to a group of children (e.g. only the girls).	Connect a specific fine motor reaction with a verbal command, inhibit prepotent motor reactions, adapt to rule changes, find solutions for the "opposite" hand movement
Three Chinamen with a double bass	Practice the song *Three Chinamen with a double bass*. After practice, sing the song with different vocals in response to a verbal command. As an additional rule, a visual signal for the different vocals (green, red and yellow card) is added instead of the verbal command.	Remember lyrics, inhibit prepotent responses, connect a reaction with a verbal or visual command, adapt to rule changes

children were instructed to sort the cards according to their shape if they had a black border, and to otherwise sort them according to their color. The border version started with a practice trial and was followed by 12 trials. Again, the rules were repeated on each trial. Performance in the DCCS was measured as the total number of correctly solved trials. Evidence for the acceptable reliability and construct validity of the DCCS border version has been proven, with same-day test–retest reliability of $ICC = 0.90$ in a sample of 4.5 year old children (Beck, Schaefer, Pang, & Carlson, 2011) and with correlations of $r = 0.53$ between the DCCS and the head-toes-knees-shoulders task in a sample of 151 kindergarten children (McClelland et al., 2014).

2.7. Statistical analyses

To account for the hierarchical data structure with children being clustered within their classes, multilevel analyses were conducted (using the linear mixed-effects models procedure of the IBM SPSS software; SPSS 26.0). A two-level structure was applied, with children ($n = 189$) at the first level, and class ($n = 14$) at the second level. In the model of the manipulation check analysis, group was treated as fixed effect and class as random effect. In all the models of the main analyses, time, group and the group-by-time interaction were treated as fixed effects and class as random effect. These models of the main analyses were specified accordingly to adjust for potential baseline imbalances (Twisk et al., 2018). Since repeated measures designs result in correlated error terms within a subject, a block diagonal matrix was chosen, where each block is a first-order autoregressive (AR1) covariance matrix. Besides being recommended for repeatedly measured variables, in which the correlation between the measurements decrease with increasing lag (Littell, Pendergast, & Natarajan, 2000), this choice also led

Table 4
Results of the multilevel models with experimental condition as the independent variable and steps per minute as well as the core executive functions as dependent variables.

Random Effects Level	Effect	Parameter Estimate	Standard Error	Wald *Z*	*p*	95% C.I.	
						Lower	*Upper*
Steps per minute							
Class	Intercept	97.69	39.35	2.48	**.013**	44.35	215.14
Enjoyment							
Class	Intercept	0.01	0.02	0.89	.373	0.00	0.12
Updating (accuracy)							
Class	Intercept	3.87	1.95	1.98	**.048**	1.44	10.41
Inhibition (accuracy)							
Class	Intercept	0.00	0.00	1.14	.253	0.00	0.00
Inhibition (RT)							
Class	Intercept	167504.07	80954.57	2.07	**.039**	64959.16	431926.98
Shifting (accuracy)							
Class	Intercept	.	.	.	.	.	.

Fixed Effects Effect	**Parameter Estimate**	**Standard Error**	**Approx df**	***t* ratio**	***p***	**95% C.I.**	
						Lower	*Upper*
Steps per minute							
Physical-cognitive	31.92	6.88	13.35	4.64	< **.0005**	17.10	46.74
Cognitive	−3.63	6.82	12.85	−0.53	.604	−18.40	11.13
Control[a]	0	0	.	.	.	.	.
Enjoyment							
Physical-cognitive	0.00	0.11	14.92	0.03	.980	−0.24	0.24
Cognitive[a]	0	0	.	.	.	.	.
Updating (accuracy)							
Time	−0.22	0.64	363.68	−0.34	.732	−1.48	1.04
Physical-cognitive	1.41	1.54	14.28	0.91	.375	−1.89	4.72
Cognitive	1.38	1.60	15.98	0.86	.401	−2.01	4.77
Time*physical-cognitive	−1.87	0.86	363.68	−2.17	**.032**	−3.57	−0.17
Time*cognitive	−2.86	0.94	363.68	−3.03	**.003**	−4.72	−1.00
Inhibition (accuracy)							
Time	−0.07	0.03	359.67	−2.11	**.036**	−0.14	−0.00
Physical-cognitive	0.02	0.04	21.97	0.48	.634	−0.06	0.10
Cognitive	0.02	0.04	27.06	0.34	.734	−0.07	0.10
Time*physical-cognitive	−0.01	0.04	359.67	−0.26	.796	−0.10	0.08
Time*cognitive	0.01	0.05	359.67	0.27	.791	−0.09	0.11
Inhibition (RT)							
Time	383.91	143.96	364.01	2.67	**.008**	100.81	667.00
Physical-cognitive	123.60	304.76	16.45	0.41	.690	−521.01	768.21
Cognitive	478.70	291.36	12.40	1.64	.125	−153.84	1111.25
Time*physical-cognitive	25.56	194.56	364.01	0.13	.896	−357.06	408.18
Time*cognitive	−11.81	213.15	364.01	−0.06	.956	−430.97	407.36
Shifting (accuracy)							
Time	−1.47	1.12	378	−1.32	.189	−3.66	0.73
Physical-cognitive	−0.75	1.07	378	−0.70	.485	−2.84	1.35
Cognitive	−0.60	1.17	378	−0.52	.607	−2.90	1.70
Time*physical-cognitive	−1.04	1.51	378	−0.69	.492	−4.00	1.93
Time*cognitive	−0.82	1.65	378	−0.50	.620	−4.07	2.43

Note. [a]Except for enjoyment, in all analyses, the control condition served as the reference group. Significant p-values ($p < .05$) are marked in bold.

to better model fit indices, using the Akaike information criterion (AIC), than applying the unstructured (UN) or the more "liberal" compound symmetry (CS) covariance structure.

To test whether the full model in which the class was included as a random intercept, fitted the data significantly better than the "basic" model, a χ^2 difference test was used with −2 Log-Likelihood as the information criterion. The model with the best fit was subsequently chosen. When the fixed effect of interest was significant, the control group used set as the reference group to test for between-group differences. The pattern of results did not change when using one of the other two groups instead. The level of significance was set at $p < .05$ for all analyses.

3. Results

3.1. Manipulation check

The linear mixed model showed that there was a significant difference between the experimental conditions in children's step counts per minute, $F(2, 13.93) = 17.73$, $p < .0005$. Parameter estimates and statistics are presented in Table 4. Post hoc comparisons revealed that the physical-cognitive condition was more physically exerting than the control condition, $t(13.35) = 4.64$, $p < .0005$. The cognitive condition, however, did not differ from the control condition, $t(12.85) = -0.53$, $p = .604$.

As revealed by the linear mixed model including only the two conditions receiving an intervention, the physical-cognitive and the cognitive training did not elicit different enjoyment in the participating children, $F(1, 14.92) = 0.00$, $p = .980$.

3.2. Main analyses

Multiple χ^2 difference tests revealed that the full model (including the class as second-level factor) fitted the data significantly better than the intercepts-only model for updating, χ^2 (2, $N = 189$) = 2302.59 – 2241.58 = 61.01, $p < .05$, and inhibition reaction time, χ^2 (2, $N = 189$) = 6212.91 – 6146.86 = 66.05, $p < .05$, but not for inhibition accuracy, χ^2 (2, $N = 189$) = -168.08 – −164.45 = 3.63, $p > .05$, and shifting, χ^2 (2, $N = 189$) = 2454.05 – 2449.89 = 4.16, $p > .05$.

For updating, the linear mixed model showed that there was a significant group-by-time interaction, $F(2, 363.68) = 4.87$, $p = .009$. Parameter estimates and statistics are presented in Table 4. Post hoc comparisons showed that the children from both the physical-cognitive, $t(363.68) = -2.17$, $p = .032$, and the cognitive training, $t(363.68) = -3.03$, $p = .003$, improved more in their updating performance than those from the control group.

For inhibition, the linear mixed model revealed no significant group-by-time interaction for both the reaction time score of inhibition, $F(2, 364.01) = 0.02$, $p = .982$, and the accuracy score of inhibition, $F(2, 359.67) = 0.14$, $p = .872$.

For shifting, the model including the class at the second level has not converged, due to the Hessian matrix not being positive definite. Therefore, the reported results are based on the basic model. There was no significant group-by-time interaction for shifting, $F(2, 378) = 0.25$, $p = .777$.

4. Discussion

In the present study, we tested the assumption that a six-week combined physical-cognitive training benefits kindergarten children's EFs more than a six-week sedentary cognitive training. We also assumed that the EFs of children in both training groups would improve more in comparison to a waiting control group. The results partially supported our assumptions, as updating improved significantly in the training groups compared to the waiting control group. However, there was no statistically significant improvement in inhibition and shifting. These results suggest that playful group-based interventions (conceptualized as indirect trainings) are suitable to foster specific EFs, regardless of with or without physical activity. Specifically, involving kindergarten children in short (15 min) challenging tasks four times a week for a period of six weeks leads to better EF performance, especially in updating. From an applied perspective, the current findings suggest that in order to promote EFs, it does not matter if the children participate in a combined physical-cognitive training or in a sedentary cognitive training, as long as they train their EFs. However, in order to foster EFs and to add physical activity to kindergarten children's school day, the implementation of a combined physical-cognitive training seems the most promising way, since this condition has induced significantly more objectively measured step counts than the cognitive or control condition.

4.1. Effects of the combined physical-cognitive training

In the current study, kindergarten children's core EFs (i.e., updating, inhibition, and shifting) were assessed, and selective effects were found only for updating in both the *physical-cognitive* and the *cognitive condition*. This is a particularly interesting finding taking into account that updating has rarely been examined for this age group, with the effects of both acute and chronic physical activity on updating presenting inconclusive results in child and adolescent samples (Barenberg, Berse, & Dutke, 2011). This selective effect can be discussed in light of developmental changes occurring in the EFs during childhood.

Disentangling the development of EFs, an initially undifferentiated and unfractionated form of EFs skills proceeding to a more integrated model during the preschool years (Howard, Okely, & Ellis, 2015). Specifically, updating, inhibition, and shifting show a direct and interconnected relationship in the early years of life, while they are gradually turned into specific and discrete skills by the early years of primary school (Brydges, Fox, Reid, & Anderson, 2014; Howard et al., 2015). These separate functions have a similar performance and influence each other (Howard et al., 2015), but different structures may be observed during preschool, primary school, and adolescent years (Best & Miller, 2010). Hence, the developmental trajectory of EFs in the early years commences with qualitative changes related to cognitive function, and concludes with more quantitative changes related to enhancing these abilities (Best & Miller, 2010). The most significant amendments can occur between 5 and 8 years, until reaching a stable and stagnant period of early adulthood (Best, Miller, & Naglieri, 2011; Huizinga, Dolan, & van der Molen, 2006). To this vein, inhibition and updating are fully developed earlier (Davidson, Amso, Anderson, & Diamond, 2006) and should be less easily affected compared to shifting; the last EF to be fully developed, grounded on updating and inhibition (Diamond, 2013).

The current literature on cognitively challenging physical activity and cognition has found selective effects, concluding that physical activity interventions can improve EFs in children. However, EFs are not all changed in the same way. For instance, *shifting* seems to be easier to include in a physical activity task, as it entails a quick response between several tasks. Consequently, it may be more sensitive to positive changes through physical activity. A 6-month cognitively enriched physical education intervention revealed improved shifting performance in children aged 5–10 years (Pesce et al., 2013). Similarly, shifting was boosted when 10–12 years children participated in a 6-week program that involved high level of physical exertion and cognitive engagement, compared to the aerobic exercise and control group (Schmidt et al., 2015), or when younger children of 7–9 years were involved with cognitively engaging classroom-based physical activity for 20-weeks (Egger et al., 2019). Overall, positive effects on shifting were found in chronic physical activity interventions. However, an acute bout of classroom-based physical activity was found to impede shifting performance in 7–9 year old children (Egger et al., 2018).

Regarding other EFs, *inhibition* and *updating* were improved when overweight children (9–10 years) completed a 6-month physical education program, including cognitively demanding physical activity (Crova, Marchetti, Struzzolino, Forte, & Pesce, 2014). In the study of Van der Niet et al. (2016), a 22-week cognitively demanding aerobic intervention during recess also produced enhanced inhibition and updating performance compared to a passive control group in 8- to 12-year-olds. And in conducting an 8-week coordinative exercise intervention with different exercise intensities in kindergarten children, Chang et al. (2013) found shorter reaction times and higher response accuracy in the Eriksen flanker test measuring children's inhibition. These results align with results from reviews and *meta*-analyses showing that inhibition is the EF domain that is the easiest to be influenced by physical activity, with positive effects found in children (Álvarez-Bueno et al., 2017; Barenberg et al., 2011), as well as adults (Kramer, Erickson, & Colcombe, 2006).

Contrary to the beliefs that inhibition and shifting may be more receptive to changes occurring through physical activity, the current study did not find differences in these dimensions. The timeframe used in previous chronic cognitively challenging physical activity interventions that found positive effects varied between two (Chang et al., 2013) and six months (Pesce et al., 2013), while one study had 6-weeks (Schmidt et al., 2015). The population used in these studies was primary school children. Possibly, the duration of the intervention implies that more time is needed for preschool children to provoke variations in these specific EFs. Alternatively, during the different stages of development, changes occurring in the working memory are more related to one component than another, or the brain activity pattern linked to one component over the other may differ based on the age-related changes (Brahmbhatt, White, & Barch, 2010).

4.2. Effects of the cognitive training

Positive effects on updating were also shown in the *cognitive condition*. Further investigating the effects of mere cognitive training on children's EFs (with the absence of physical activity), multimodal approaches (i.e., indirect training) have been found to be more effective (Takacs & Kassai, 2019) than approaches including only one-dimension (i.e., direct training) e.g. computerized working memory training (Bergman Nutley et al., 2011; Klingberg et al., 2002). Interestingly, computer-based or school curricula activities can enhance EFs in children as young as preschool (Diamond & Lee, 2011; Diamond & Ling, 2016). For example, chronic trainings lasting 4 or 6 weeks have been found to improve all core EF skills in preschool children (Röthlisberger et al., 2011; Traverso et al., 2015). In addition, improvements in updating and shifting were observed in 10–12 year old children after 6 weeks of cognitive training comprising card and board games (Benzing et al., 2018). These approaches incorporated adaptive, challenging games with exposure to different and continuously changing situations for updating of information and adaptation to new situations (Blair & Diamond, 2008; Diamond & Lee, 2011). Regarding inhibition, the efficacy of interventions is more ambiguous, with few school programs having found positive effects (Blair & Raver, 2014; Diamond et al., 2007), and others including computerized training reporting null effects (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009). Overall, the indirect trainings may elicit larger transfer effects and smaller training gains (Takacs & Kassai, 2019). In contrast, direct trainings promote smaller transfer effects but larger training gains, with the majority of school-based interventions focusing only on one EF domain (Cardoso et al., 2018; Diamond & Lee, 2011; Otero et al., 2014).

As such, the advantage of the present study lies on the fact that a combination of both direct and indirect training was used. The *physical-cognitive* and the *cognitive condition* targeted the three core EFs (i.e., updating, inhibition, and shifting) along with self-regulations skills arising from attention to the tasks' orders or rules, team collaboration, emotion regulation, and in turn, successful game play. Consistent with the study of Mackey et al. (2011), this study included both computerized and non-computerized training, showing that cognitive training can be modified and ameliorate children's cognitive skills. Even if positive effects in untrained computerized task performance in updating were noted, it still remains unclear how the combination of different elements of the tasks influenced transfer effects. The selective effect in updating, however, is meaningful, since updating can significantly predict math achievement (Bull & Lee, 2014; Bull & Scerif, 2001), in contrast to shifting and inhibition being less conclusive. Thus, the current study presents a unique contribution on fostering EFs in kindergarten children, more precisely the core EF of updating, through a cognitive and a combined physical-cognitive intervention.

In general, EFs are fundamental for physical and mental health, cognition, psychological, emotional, and social development, as well as academic success (Diamond, 2013). EFs are estimated to be even "more important for school readiness than intelligence quotient" (Diamond & Lee, 2011, p. 959), with evidence showing that EFs have been associated with early literacy and numeracy competence (Blair & Razza, 2007), which can be maintained during the first three years of schooling (Bull et al., 2008).

4.3. Effects on children's step counts and enjoyment

The combined physical-cognitive training has led to a higher amount of objectively measured step counts per minute than the cognitive or control condition. The integration of movement experiences into learning areas such as math or language in preschool children results in children being more physically active, attentive, and enthusiastic, and have higher learning scores compared to children in sedentary control groups (Mavilidi, Okely, Chandler, Cliff, & Paas, 2015; Mavilidi, Okely, Chandler, Domazet, & Paas, 2018; Mavilidi, Okely, Chandler, & Paas, 2016, 2017; Mavilidi, Ruiter, et al., 2018; Toumpaniari, Loyens, Mavilidi, & Paas, 2015). Increases in children's physical activity levels and academic outcomes have also been found in primary school children (Donnelly et al., 2016), confirming the tenet that stealth interventions for promoting physical activity are highly effective (Robinson, 2010).

Such interventions mostly promote moderate-to-vigorous physical activity in children (Mavilidi et al., 2015, 2016, 2017; Mavilidi, Okely, et al., 2018; Mavilidi, Ruiter, et al., 2018). In order to elicit cognitive changes and promote children's cognitive functions, acute bouts of moderate-to-vigorous physical activity are required with heart rates reaching 70–85% (Chang, Labban, Gapin, & Etnier, 2012). Regarding intensity, physical activity has improved EFs when the heart rate reaches up to 120 bpm in adolescents (Budde et al., 2008) and 160 bpm in children aged 9–10 years (Best, 2012). In terms of duration, acute physical activity breaks lasting from 10 to 50 min have shown positive effects on children's attention (Budde et al., 2008; Gallotta et al., 2012, 2015; Hill et al., 2010; Schmidt et al., 2016). Alternatively, physiological changes provoked by chronic physical activity have also been found to positively affect children's cognitive functioning (Drollette, Shishido, Pontifex, & Hillman, 2012). In this study, positive effects were only found for updating. Future studies including higher intensity of physical activity would more likely be able to show additional cognitive benefits in the age group studied (i.e., kindergarten children).

Nonetheless, physical activity recommendations worldwide suggest that children from 5 years should spend at least 60 min of daily physical activity to ensure health outcomes (Australian Government Department of Health (2017) ()2017, 2017; Canadian Society for Exercise Physiology (2017) ()()2017, 2017, 2017; Centers for Disease Control and Prevention, 2016; Institute of Medicine, 2011; World Health Organization (2018) ()()2018, 2018, 2018), while the recommended time increases to 180 min of physical activity per day for younger ages (0–5 years, Australian Government Department of Health (2017) () 2017, 2017; 1–4 years, Canadian Society for Exercise Physiology (2017) ()()2017, 2017, 2017). Importantly, the Institute of Medicine (2011) recommends that all childcare providers should offer preschool children with opportunities for physical activity throughout the day (i.e., moderate-to-vigorous physical activity for at least 15 min per hour while children are in care), decreasing the time that children spend sitting or standing (i.e., limiting sitting or standing to no more than 30 min at a time). Unfortunately, research has shown that preschool children spend around 73% of their waking hours in sedentary behavior (Salmon, Tremblay, Marshall, & Hume, 2011), while 48.4% of their time in childcare is spent sitting (Ellis et al., 2017). These behavioral patterns are evident in children as young as 3–5 years, but also for 5–8 year old's (Jones, Hinkley, Okely, & Salmon, 2013).

Considering the low levels of physical activity reported in childcares (Reilly, 2010), although in this study we were not able to infer regarding the intensity level, this intervention comes closer to the physical activity recommendations, offering both cognitive and physiological benefits. This study, therefore, might be of practical relevance in the development of a low-cost intervention for the field of education. Exploring the long-term effect on children's academic achievement, motivation towards the school, and general mental health could be worthwhile to investigate in future research.

Finally, results from the enjoyment scale showed no significant differences among the two interventions, indicating that the interventions did not seem to differ in this potential confounding variable. Since, however, we did not measure enjoyment in the control condition, we cannot rule out the possibility that the intervention effects were partly due to enhanced enjoyment or motivation. Intrinsic motivation, focusing on the enjoyment of the learning activity itself has been linked to learning, creativity, and school achievement (Robinson et al., 2017; Ryan & Deci, 2000; Schmidt et al., 2019). It is also important to note the importance of "play" during preschool years for children's cognitive, social and psychological development (Duncan & Tarulli, 2003). As Schwartzman (1978) noted: "Play is first of all assumed to be pleasurable and enjoyable, to be characterized by freedom and spontaneity, and to elicit active (as opposed to passive) engagement by players [...] its motivations are said to be intrinsic as opposed to extrinsic" (p. 327). As such, age-appropriate activities tend to be game-based and have a more playful and enjoyable character, while most tasks given to kindergarten children inherently include the factor of enjoyment.

As pointed out by Diamond and Lee (2011, p. 963): "The best approaches to improving EFs and school outcomes will probably be those that (a) engage students' passionate interests, bringing them joy and pride, (b) address stresses in students' lives, attempting to resolve external causes and strengthen calmer, healthier responses, (c) have students vigorously exercise, and (d) give students a sense of belonging and social acceptance, in addition to giving students opportunities to repeatedly practice EFs at progressively more-advanced levels."

4.4. Limitations and future directions

For the sake of ecological validity, the randomization was done on a class instead of an individual level. This might have been one reason why baseline-imbalance had to be reported in the reaction time component of inhibition. Field studies have to deal with the trade-off between internal and external validity, whilst in the current study we tried to represent the real world setting as much as possible to give preference to the external validity. Future studies, however, could randomize on an individual level, allowing to adjust both the cognitive challenge and the physical exertion on an individual level. One might speculate that in doing so, the effect sizes of the interventions would rise.

Another limitation is the fact that each core EF has been assessed by only one task. Since selective effects on different core EFs have been reported, we wanted to cover all three core EFs with the chosen test battery, as proposed by Miyake et al. (2000). Including at least two tasks per core EF would have been more appropriate to face the task-impurity problem, which is that any core EF is measured by a task including not only variance of EF processes but also non-EF processes (Miyake & Friedman, 2012). However, using multiple tasks during the testing bears the risk of washing out potential intervention effects induced by the fatigue resulted out of the multiple tests. In future, studies could therefore use multiple tasks and spread over several days of testing.

The physical-cognitive intervention was compared to a pure cognitive intervention and to an active control group, but not to a pure physical intervention. Firstly, we need to acknowledge that both interventions developed for kindergarten children were characterized by a lot of novel fine or gross motor activities, inducing a considerable amount of enjoyment in the children. Hence, it is not easy to decipher the clear physical and cognitive advantage on EFs, since novelty is thought to induce enjoyment and has also been identified as a critical component of training programs fostering cognitive functioning (Moreau & Conway, 2013). Future studies should therefore explore the role of enjoyment and task novelty as potential mediators in the relationship between physical activity and cognition in children. Second, with this chosen design we cannot rule out the possibility that simple aerobic exercise would have resulted in the same effects. However, since both the interventions have led to improvements in the same core EF with comparable effect sizes, it is quite convincing that this effect is driven by the cognitive and not the physical component of the training. Thus, to disentangle the cognitive from the physical component, using 2x2 designs would be the design of choice for future studies, as mostly used in acute physical activity and cognition studies (Best, 2012; Jäger et al., 2015; Schmidt et al., 2016). In addition, designing high-quality intervention studies on physical activity that target specific EFs and its underlying mechanisms is indispensable (Singh et al., 2019).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to thank the participating teachers and students and we also wish to acknowledge the help of our bachelor's and master's students (Larissa Böhlen, Yannik Escher, and Maja Kelava) with collecting the data. Thanks are also due to Amie Wallman-Jones for her last minute proofreading. This research was supported by the Swiss National Science Foundation (SNSF; grant number IZSEZ0_178014).

References

Álvarez-Bueno, C., Pesce, C., Cavero-Redondo, I., Sánchez-López, M., Martínez-Hortelano, J. A., & Martínez-Vizcaíno, V. (2017). The effect of physical activity interventions on children's cognition and metacognition: A systematic review and meta-analysis. *Journal of the American Academy of Child and Adolescent Psychiatry, 56*(9), 729–738. https://doi.org/10.1016/j.jaac.2017.06.012.

Anastasopoulou, P., Tubic, M., Schmidt, S., Neumann, R., Woll, A., & Härtel, S. (2014). Validation and comparison of two methods to assess human energy expenditure during free-living activities. *PLoS ONE, 9*(2), Article e90606. https://doi.org/10.1371/journal.pone.0090606.

Audiffren, M., Tomporowski, P. D., & Zagrodnik, J. (2009). Acute aerobic exercise and information processing: Modulation of executive control in a random number generation task. *Acta Psychologica, 132*(1), 85–95. https://doi.org/10.1016/j.actpsy.2009.06.008.

Australian Government Department of Health (2017). Australia's physical activity and sedentary behaviour guidelines. Commonwealth of Australia. Retrieved July 13, 2018 from: http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-strateg-phys-act-guidelines#npa05.

Barenberg, J., Berse, T., & Dutke, S. (2011). Executive functions in learning processes: Do they benefit from physical activity? *Educational Research Review, 6*(3), 208–222. https://doi.org/10.1016/j.edurev.2011.04.002.

Beck, D. M., Schaefer, C., Pang, K., & Carlson, S. M. (2011). Executive function in preschool children: Test-retest reliability. *Journal of Cognition and Development, 12*(2), 169–193. https://doi.org/10.1080/15248372.2011.563485.

Benzing, V., Heinks, T., Eggenberger, N., & Schmidt, M. (2016). Acute cognitively engaging exergame-based physical activity enhances executive functions in adolescents. *PLoS ONE, 11*(12), Article e0167501. https://doi.org/10.1371/journal.pone.0167501.

Benzing, V., Schmidt, M., Jäger, K., Egger, F., Conzelmann, A., & Roebers, C. M. (2018). A classroom intervention to improve executive functions in late primary school children: Too 'old' for improvements? Advance online publication *The British Journal of Educational Psychology*. https://doi.org/10.1111/bjep.12232.

Bergman Nutley, S., Söderqvist, S., Bryde, S., Thorell, L. B., Humphreys, K., Klingberg, T., ... Klingberg, T. (2011). Gains in fluid intelligence after training non-verbal reasoning in 4-year-old children: A controlled, randomized study. *Developmental Science, 14*(3), 591–601. https://doi.org/10.1111/j.1467-7687.2010.01022.x.

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*(4), 331–351. https://doi.org/10.1016/j.dr.2010.08.001.

Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental Psychology, 48*(5), 1501–1510. https://doi.org/10.1037/a0026648.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development, 81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x.

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences, 21*(4), 327–336. https://doi.org/10.1016/j.lindif.2011.01.007.

Blair, C., & Diamond, A. (2008). Biological processes in prevention and intervention: The promotion of self-regulation as a means of preventing school failure. *Development and Psychopathology, 20*(3), 899–911. https://doi.org/10.1017/s0954579408000436.

Blair, C., & Raver, C. C. (2014). Closing the achievement gap through modification of neurocognitive and neuroendocrine function: Results from a cluster randomized controlled trial of an innovative approach to the education of children in kindergarten. *PLoS ONE, 9*(11), Article e112393. https://doi.org/10.1371/journal.pone.0112393.

Blair, C., & Razza, R. P. (2007). Relating Effortful Control, Executive Function, and False Belief Understanding to Emerging Math and Literacy Ability in Kindergarten. *Child Development, 78*(2), 647–663. https://doi.org/10.1111/j.1467-8624.2007.01019.x.

Bodrova, E., & Leong, D. J. (2007). *Tools of the mind: The Vygotskian approach to early*

childhood education. New York: Merrill/Prentice-Hall.
Brahmbhatt, S. B., White, D. A., & Barch, D. M. (2010). Developmental differences in sustained and transient activity underlying working memory. *Brain Research, 1354*, 140–151. https://doi.org/10.1016/j.brainres.2010.07.055.
Brydges, C. R., Fox, A. M., Reid, C. L., & Anderson, M. (2014). The differentiation of executive functions in middle and late childhood: A longitudinal latent-variable analysis. *Intelligence, 47*, 34–43. https://doi.org/10.1016/j.intell.2014.08.010.
Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., Tidow, G., Pietrabyk-Kendziorra, S., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*(2), 219–223. https://doi.org/10.1016/j.neulet.2008.06.024.
Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33*(3), 205–228. https://doi.org/10.1080/87565640801982312.
Bull, R., & Lee, K. (2014). Executive functioning and mathematics achievement. *Child Development Perspectives, 8*(1), 36–41. https://doi.org/10.1111/cdep.12059.
Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*(3), 273–293.
Canadian Society for Exercise Physiology (2017). Canadian 24-hour movement guidelines. Ontario, Canada. Retrieved July 13, 2018 from: http://csepguidelines.ca/.
Cardoso, C.d. O., Dias, N., Senger, J., Colling, A. P. C., Seabra, A. G., & Fonseca, R. P. (2018). Neuropsychological stimulation of executive functions in children with typical development: A systematic review. *Applied Neuropsychology. Child, 7*(1), 61–81. https://doi.org/10.1080/21622965.2016.1241950.
Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology, 28*(2), 595–616. https://doi.org/10.1207/s15326942dn2802_3.
Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development, 72*(4), 1032–1053. https://doi.org/10.1111/1467-8624.00333.
Carroll, C., Patterson, M., Wood, S., Booth, A., Rick, J., & Balain, S. (2007). A conceptual framework for implementation fidelity. *Implementation Science, 2*, 40. https://doi.org/10.1186/1748-5908-2-40.
Centers for Disease Control and Prevention (2016). Cancer prevention and control. Current physical activity guidelines. Atlanta, USA. Retrieved July 13, 2018 from: https://www.cdc.gov/cancer/dcpc/prevention/policies_practices/physical_activity/guidelines.htm.
Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453*, 87–101. https://doi.org/10.1016/j.brainres.2012.02.068.
Chang, Y.-K., Tsai, Y.-J., Chen, T.-T., & Hung, T.-M. (2013). The impacts of coordinative exercise on executive function in kindergarten children: An ERP study. *Experimental Brain Research, 225*(2), 187–196. https://doi.org/10.1007/s00221-012-3360-9.
Crova, C., Marchetti, R., Struzzolino, I., Forte, R., & Pesce, C. (2014). Training attention in physical education: Effects on typically developing and DCD children. *Procedia - Social and Behavioral Sciences, 116*, 1509–1512. https://doi.org/10.1016/j.sbspro.2014.01.425.
Dane, A. V., & Schneider, B. H. (1998). Program integrity in primary and early secondary prevention: Are implementation effects out of control? *Clinical Psychology Review, 18*(1), 23–45.
Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*(11), 2037–2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006.
De Craemer, M., de Decker, E., Santos-Lozano, A., Verloigne, M., de Bourdeaudhuij, I., Deforche, B., & Cardon, G. (2015). Validity of the Omron pedometer and the actigraph step count function in preschoolers. *Journal of Science and Medicine in Sport, 18*(3), 289–293. https://doi.org/10.1016/j.jsams.2014.06.001.
De Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2016). Long-term effects of physically active academic lessons on physical fitness and executive functions in primary school children. *Health Education Research, 31*(2), 185–194. https://doi.org/10.1093/her/cyv102.
Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development, 71*(1), 44–56. https://doi.org/10.1111/1467-8624.00117.
Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750.
Diamond, A. (2015). Effects of physical exercise on executive functions: Going beyond simply moving to moving with thought. *Annals of Sports Medicine and Research, 2*(1), 1011.
Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). The early years. Preschool program improves cognitive control. *Science, 318*(5855), 1387–1388. https://doi.org/10.1126/science.1151148.
Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333*(6045), 959–964. https://doi.org/10.1126/science.1204529.
Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience, 18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005.
Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "Do as I say, not as I do". *Developmental Psychobiology, 29*(4), 315–334. https://doi.org/10.1002/(SICI)1098-2302(199605)29:4 < 315::AID-DEV2 > 3.0.CO;2-T.
Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., ... Szabo-Reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: A systematic review. *Medicine and Science in Sports and Exercise, 48*(6), 1223–1224. https://doi.org/10.1249/MSS.0000000000000966.
Drollette, E. S., Shishido, T., Pontifex, M. B., & Hillman, C. H. (2012). Maintenance of cognitive control during and after walking in preadolescent children. *Medicine & Science in Sports & Exercise, 44*(10), 2017–2024. https://doi.org/10.1249/MSS.0b013e318258bcd5.
Duncan, R. M., & Tarulli, D. (2003). Play as the Leading Activity of the Preschool Period: Insights from Vygotsky, Leont'ev, and Bakhtin. *Early Education & Development, 14*(3), 271–292. https://doi.org/10.1207/s15566935eed1403_2.
Egger, F., Benzing, V., Conzelmann, A., & Schmidt, M. (2019). Boost your brain, while having a break! The effects of long-term cognitively engaging physical activity breaks on children's executive functions and academic achievement. *PLoS ONE, 14*(3), Article e0212482. https://doi.org/10.1371/journal.pone.0212482.
Egger, F., Conzelmann, A., & Schmidt, M. (2018). The effect of acute cognitively engaging physical activity breaks on children's executive functions: Too much of a good thing? *Psychology of Sport and Exercise, 36*, 178–186. https://doi.org/10.1016/j.psychsport.2018.02.014.
Ellis, Y. G., Cliff, D. P., Janssen, X., Jones, R. A., Reilly, J. J., & Okely, A. D. (2017). Sedentary time, physical activity and compliance with IOM recommendations in young children at childcare. *Preventive Medicine Reports, 7*, 221–226. https://doi.org/10.1016/j.pmedr.2016.12.009.
Espy, K. A., Sheffield, T. D., Wiebe, S. A., Clark, Caron A. C., & Moehr, M. J. (2011). Executive control and dimensions of problem behaviors in preschool children. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 52*(1), 33–46. https://doi.org/10.1111/j.1469-7610.2010.02265.x.
Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191.
Friedman, N. P., Haberstick, B. C., Willcutt, E. G., Miyake, A., Young, S. E., Corley, R. P., & Hewitt, J. K. (2007). Greater attention problems during childhood predict poorer executive functioning in late adolescence. *Psychological Science, 18*(10), 893–900. https://doi.org/10.1111/j.1467-9280.2007.01997.x.
Gallotta, M. C., Emerenziani, G. P., Franciosi, E., Meucci, M., Guidetti, L., & Baldari, C. (2015). Acute physical activity and delayed attention in primary school students. *Scandinavian Journal of Medicine & Science in Sports, 25*(3), 331–338. https://doi.org/10.1111/sms.12310.
Gallotta, M. C., Guidetti, L., Franciosi, E., Emerenziani, G. P., Bonavolontà, V., Baldari, C., & Bonavolonta, V. (2012). Effects of varying type of exertion on children's attention capacity. *Medicine & Science in Sports & Exercise, 44*(3), 550–555. https://doi.org/10.1249/MSS.0b013e3182305552.
Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3 1/2-7 years old on a stroop-like day-night test. *Cognition, 53*(2), 129–153. https://doi.org/10.1016/0010-0277(94)90068-X.
Herold, F., Hamacher, D., Schega, L., & Müller, N. G. (2018). Thinking while moving or moving while thinking - Concepts of motor-cognitive training for cognitive performance enhancement. *Frontiers in Aging Neuroscience, 10*, 228. https://doi.org/10.3389/fnagi.2018.00228.
Hill, L., Williams, J. H. G., Aucott, L., Milne, J., Thomson, J., Greig, J., ... Mon-Williams, M. (2010). Exercising attention within the classroom. *Developmental Medicine & Child Neurology, 52*(10), 929–934. https://doi.org/10.1111/j.1469-8749.2010.03661.x.
Hillman, C. H., & Biggan, J. R. (2017). A review of childhood physical activity, brain, and cognition: Perspectives on the future. *Pediatric Exercise Science, 29*(2), 170–176. https://doi.org/10.1123/pes.2016-0125.
Hillman, C. H., Kamijo, K., & Scudder, M. (2011). A review of chronic and acute physical activity participation on neuroelectric measures of brain health and cognition during childhood. *Preventive Medicine, 52*, S21–S28. https://doi.org/10.1016/j.ypmed.2011.01.024.
Howard, S. J., Okely, A. D., & Ellis, Y. G. (2015). Evaluation of a differentiation model of preschoolers' executive functions. *Frontiers in Psychology, 6*, 285. https://doi.org/10.3389/fpsyg.2015.00285.
Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia, 44*(11), 2017–2036. https://doi.org/10.1016/j.neuropsychologia.2006.01.010.
Institute of Medicine (2011). Early childhood obesity prevention policies. Washington, DC. Retrieved July 13, 2018 from: http://www.nationalacademies.org/hmd/~/media/Files/Report%20Files/2011/Early-Childhood-Obesity-Prevention-Policies/Young%20Child%20Obesity%202011%20Recommendations.pdf.
Jäger, K., Schmidt, M., Conzelmann, A., & Roebers, C. M. (2014). Cognitive and physiological effects of an acute physical activity intervention in elementary school children. *Frontiers in Psychology, 5*, 71. https://doi.org/10.3389/fpsyg.2014.01473.
Jäger, K., Schmidt, M., Conzelmann, A., & Roebers, C. M. (2015). The effects of qualitatively different acute physical activity interventions in real-world settings on executive functions in preadolescent children. *Mental Health and Physical Activity, 9*, 1–9. https://doi.org/10.1016/j.mhpa.2015.05.002.
Johansson, E., Larisch, L.-M., Marcus, C., & Hagströmer, M. (2016). Calibration and validation of a wrist- and hip-worn actigraph accelerometer in 4-year-old children. *PLoS ONE, 11*(9), Article e0162436. https://doi.org/10.1371/journal.pone.0162436.
Jones, R. A., Hinkley, T., Okely, A. D., & Salmon, J. (2013). Tracking physical activity and sedentary behavior in childhood: A systematic review. *American Journal of Preventive Medicine, 44*(6), 651–658. https://doi.org/10.1016/j.amepre.2013.03.001.
Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology, 5*, 390. https://doi.org/10.3389/fpsyg.2014.00390.

Kassai, R., Futo, J., Demetrovics, Z., & Takacs, Z. K. (2019). A meta-analysis of the experimental evidence on the near- and far-transfer effects among children's executive function skills. *Psychological Bulletin, 145*(2), 165–188. https://doi.org/10.1037/bul0000180.

Khan, N. A., & Hillman, C. H. (2014). The relation of childhood physical activity and aerobic fitness to brain function and cognition: A review. *Pediatric Exercise Science, 26*(2), 138–146. https://doi.org/10.1123/pes.2013-0125.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781–791. https://doi.org/10.1076/jcen.24.6.781.8395.

Koutsandreou, F., Wegner, M., Niemann, C., & Budde, H. (2016). Effects of motor versus cardiovascular exercise training on children's working memory. *Medicine and Science in Sports and Exercise, 48*(6), 1144–1152. https://doi.org/10.1249/MSS.0000000000000869.

Kramer, A. F., Erickson, K. I., & Colcombe, S. J. (2006). Exercise, cognition, and the aging brain. *Journal of Applied Physiology, 101*, 1237–1242. https://doi.org/10.1152/japplphysiol.000500.2006.

Lee, K., Ng, S. F., Bull, R., Pe, M. L., & Ho, R. H. M. (2011). Are patterns important? An investigation of the relationships between proficiencies in patterns, computation, executive functioning, and algebraic word problems. *Journal of Educational Psychology, 103*(2), 269–281. https://doi.org/10.1037/a0023068.

Lee, K., Ng, S. F., Pe, M. L., Ang, S. Y., Hasshim, M. N. A. M., & Bull, R. (2012). The cognitive underpinnings of emerging mathematical skills: Executive functioning, patterns, numeracy, and arithmetic. *British Journal of Educational Psychology, 82*(1), 82–99. https://doi.org/10.1111/j.2044-8279.2010.02016.x.

Littell, R. C., Pendergast, J., & Natarajan, R. (2000). Modelling covariance structure in the analysis of repeated measures data. *Statistics in Medicine, 19*(13), 1793–1819. https://doi.org/10.1002/1097-0258(20000715)19:13 < 1793::AID-SIM482 > 3.0.CO;2-Q.

Little, R. J. A., & Rubin, D. B. (2002). *Statistical analysis with missing data* (2nd ed.). Wiley.

Mackey, A. P., Hill, S. S., Stone, S. I., & Bunge, S. A. (2011). Differential effects of reasoning and speed training in children. *Developmental Science, 14*(3), 582–590. https://doi.org/10.1111/j.1467-7687.2010.01005.x.

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods, 44*(2), 314–324. https://doi.org/10.3758/s13428-011-0168-7.

Mavilidi, M. F., Okely, A. D., Chandler, P., Cliff, D. P., & Paas, F. (2015). Effects of integrated physical exercises and gestures on preschool children's foreign language vocabulary learning. *Educational Psychology Review, 27*(3), 413–426. https://doi.org/10.1007/s10648-015-9337-z.

Mavilidi, M. F., Okely, A., Chandler, P., Domazet, S. L., & Paas, F. (2018). Immediate and delayed effects of integrating physical activity into preschool children's learning of numeracy skills. *Journal of Experimental Child Psychology, 166*, 502–519. https://doi.org/10.1016/j.jecp.2017.09.009.

Mavilidi, M. F., Okely, A. D., Chandler, P., & Paas, F. (2016). Infusing physical activities into the classroom: Effects on preschool children's geography learning. *Mind, Brain, and Education, 10*(4), 256–263. https://doi.org/10.1111/mbe.12131.

Mavilidi, M. F., Okely, A. D., Chandler, P., & Paas, F. (2017). Effects of integrating physical activities into a science lesson on preschool children's learning and enjoyment. *Applied Cognitive Psychology, 31*(3), 281–290. https://doi.org/10.1002/acp.3325.

Mavilidi, M. F., Ruiter, M., Schmidt, M., Okely, A. D., Loyens, S., Chandler, P., & Paas, F. (2018). A narrative review of school-based physical activity for enhancing cognition and learning: The importance of relevancy and integration. *Frontiers in Psychology, 9*, 3. https://doi.org/10.3389/fpsyg.2018.02079.

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: The head-toes-knees-shoulders task. *Frontiers in Psychology, 5*, 599. https://doi.org/10.3389/fpsyg.2014.00599.

Melby-Lervag, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49*(2), 270–291. https://doi.org/10.1037/a0028228.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21*(1), 8–14. https://doi.org/10.1177/0963721411429458.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734.

Moreau, D., & Conway, A. R. A. (2013). Cognitive enhancement: A comparative review of computerized and athletic training programs. *International Review of Sport and Exercise Psychology, 6*(1), 155–183. https://doi.org/10.1080/1750984X.2012.758763.

Morrison, A. B., & Chein, J. M. (2011). Does working memory training work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic Bulletin & Review, 18*(1), 46–60. https://doi.org/10.3758/s13423-010-0034-0.

Oberer, N., Gashaj, V., & Roebers, C. M. (2018). Executive functions, visual-motor coordination, physical fitness and academic achievement: Longitudinal relations in typically developing children. *Human Movement Science, 58*, 69–79. https://doi.org/10.1016/j.humov.2018.01.003.

Otero, T. M., Barker, L. A., & Naglieri, J. A. (2014). Executive function treatment and intervention in schools. *Applied Neuropsychology. Child, 3*(3), 205–214. https://doi.org/10.1080/21622965.2014.897903.

Pagels, P., Boldemann, C., & Raustorp, A. (2011). Comparison of pedometer and accelerometer measures of physical activity during preschool time on 3- to 5-year-old children. *Acta Paediatrica (Oslo, Norway 1992), 100*(1), 116–120. https://doi.org/10.1111/j.1651-2227.2010.01962.x.

Paschen, L., Lehmann, T., Kehne, M., & Baumeister, J. (2019). Effects of acute physical exercise with low and high cognitive demands on executive functions in children: A systematic review. *Pediatric Exercise Science, 31*(3), 267–281. https://doi.org/10.1123/pes.2018-0215.

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport & Exercise Psychology, 34*(6), 766–786. https://doi.org/10.1123/jsep.34.6.766.

Pesce, C., & Ben-Soussan, T. D. (2016). "Cogito ergo sum" or "ambulo ergo sum"? New Perspectives in Developmental Exercise and Cognition Research. In T. McMorris (Ed.). *Exercise-Cognition Interaction: Neuroscience Perspectives* (pp. 251–282). London: Elsevier. https://doi.org/10.1016/B978-0-12-800778-5.00012-8.

Pesce, C., Crova, C., Cereatti, L., Casella, R., & Bellucci, M. (2009). Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory. *Mental Health and Physical Activity, 2*(1), 16–22. https://doi.org/10.1016/j.mhpa.2009.02.001.

Pesce, C., Crova, C., Marchetti, R., Struzzolino, I., Masci, I., Vannozzi, G., & Forte, R. (2013). Searching for cognitively optimal challenge point in physical activity for children with typical and atypical motor development. *Mental Health and Physical Activity, 6*(3), 172–180. https://doi.org/10.1016/j.mhpa.2013.07.001.

Pesce, C., Masci, I., Marchetti, R., Vazou, S., Saakslahti, A., & Tomporowski, P. D. (2016). Deliberate play and preparation jointly benefit motor and cognitive development: mediated and moderated effects. *Frontiers in Psychology, 7*, 349. https://doi.org/10.3389/fpsyg.2016.00349.

Pontifex, M. B., McGowan, A. L., Chandler, M. C., Gwizdala, K. L., Parks, A. C., Fenn, K., & Kamijo, K. (2019). A primer on investigating the after effects of acute bouts of physical activity on cognition. *Psychology of Sport and Exercise, 40*, 1–22. https://doi.org/10.1016/j.psychsport.2018.08.015.

Reilly, J. J. (2010). Low levels of objectively measured physical activity in preschoolers in child care. *Medicine and Science in Sports and Exercise, 42*(3), 502–507. https://doi.org/10.1249/MSS.0b013e3181cea100.

Robinson, T. N. (2010). Stealth interventions for obesity prevention and control: Motivating behavior change. In L. Dube, A. Bechara, A. Dagher, A. Drewnowski, J. Lebel, P. James, & R. Yada (Eds.). *Obesity Prevention: The Role of Brain and Society on Individual Behavior* (pp. 319–328). New York: Elsevier.

Robinson, K. A., Ranellucci, J., Lee, Y.-K., Wormington, S. V., Roseth, C. J., & Linnenbrink-Garcia, L. (2017). Affective profiles and academic success in a college science course. *Contemporary Educational Psychology, 51*, 209–221. https://doi.org/10.1016/j.cedpsych.2017.08.004.

Roebers, C. M., & Kauer, M. (2009). Motor and cognitive control in a normative sample of 7-year-olds. *Developmental Science, 12*(1), 175–181. https://doi.org/10.1111/j.1467-7687.2008.00755.x.

Roebers, C. M., Röthlisberger, M., Neuenschwander, R., Cimeli, P., Michel, E., & Jäger, K. (2014). The relation between cognitive and motor performance and their relevance for children's transition to school: A latent variable approach. *Human Movement Science, 33*, 284–297. https://doi.org/10.1016/j.humov.2013.08.011.

Röthlisberger, M., Neuenschwander, R., Cimeli, P., Michel, E., & Roebers, C. M. (2011). Improving executive functions in 5- and 6-year-olds: Evaluation of a small group intervention in prekindergarten and kindergarten children. *Infant and Child Development, 21*(4), 411–429. https://doi.org/10.1002/icd.752.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America, 102*(41), 14931–14936. https://doi.org/10.1073/pnas.0506897102.

Ryan, & Deci (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54–67. https://doi.org/10.1006/ceps.1999.1020.

Salmon, J., Tremblay, M. S., Marshall, S. J., & Hume, C. (2011). Health risks, correlates, and interventions to reduce sedentary behavior in young people. *American Journal of Preventive Medicine, 41*(2), 197–206. https://doi.org/10.1016/j.amepre.2011.05.001.

Schmidt, R. A., & Lee, T. D. (2011). Motor control and learning: A behavioral emphasis, 5th ed. Motor control and learning: A behavioral emphasis, 5th ed. Champaign, IL, US: Human Kinetics.

Schmidt, M., Benzing, V., & Kamer, M. (2016). Classroom-based physical activity breaks and children's attention: Cognitive engagement works!. *Frontiers in Psychology, 7*, 1474. https://doi.org/10.3389/fpsyg.2016.01474.

Schmidt, M., Benzing, V., Wallman-Jones, A., Mavilidi, M.-F., Lubans, D. R., & Paas, F. (2019). Embodied learning in the classroom: Effects on primary school children's attention and foreign language vocabulary learning. *Psychology of Sport and Exercise, 43*, 45–54. https://doi.org/10.1016/j.psychsport.2018.12.017.

Schmidt, M., Egger, F., Benzing, V., Jäger, K., Conzelmann, A., Roebers, C. M., & Pesce, C. (2017). Disentangling the relationship between children's motor ability, executive function and academic achievement. *PLoS ONE, 12*(8), Article e0182845. https://doi.org/10.1371/journal.pone.0182845.

Schmidt, M., Jäger, K., Egger, F., Roebers, C. M., & Conzelmann, A. (2015). Cognitively engaging chronic physical activity, but not aerobic exercise, affects executive functions in primary school children: A group-randomized controlled trial. *Journal of Sport and Exercise Psychology, 37*(6), 575–591. https://doi.org/10.1123/jsep.2015-0069.

Schwartzman, H. B. (1978). *Transformations. The Anthropology of Children's Play.* New York: Plenum.

Scionti, N., Cavallero, M., Zogmaister, C., & Marzocchi, G. M. (2020). Is cognitive training effective for improving executive functions in preschoolers? A systematic review and meta-analysis. *Frontiers in Psychology, 10*, 2812. https://doi.org/10.3389/fpsyg.2019.02812.

Serrien, D. J., Ivry, R. B., & Swinnen, S. P. (2007). The missing link between action and cognition. *Progress in Neurobiology, 82*(2), 95–107. https://doi.org/10.1016/j.

pneurobio.2007.02.003.

Singh, A. S., Saliasi, E., van den Berg, V., Uijtdewilligen, L., de Groot, R. H. M., Jolles, J., ... Chinapaw, M. J. M. (2019). Effects of physical activity interventions on cognitive and academic performance in children and adolescents: A novel combination of a systematic review and recommendations from an expert panel: A novel combination of a systematic review and recommendations from an expert panel. *British Journal of Sports Medicine, 53*(10), 640–647. https://doi.org/10.1136/bjsports-2017-098136.

Strommen, E. A. (1973). Verbal self-regulation in a children's game: Impulsive errors on "Simon says". *Child Development, 44*(4), 849–853. https://doi.org/10.2307/1127737.

Taatgen, N. A. (2013). The nature and transfer of cognitive skills. *Psychological Review, 120*(3), 439–471. https://doi.org/10.1037/a0033138.

Takacs, Z. K., & Kassai, R. (2019). The efficacy of different interventions to foster children's executive function skills: A series of meta-analyses. Advance online publication *Psychological Bulletin*. https://doi.org/10.1037/bul0000195.

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*(1), 106–113. https://doi.org/10.1111/j.1467-7687.2008.00745.x.

Thorell, L. B., & Wåhlstedt, C. (2006). Executive functioning deficits in relation to symptoms of ADHD and/or ODD in preschool children. *Infant and Child Development, 15*(5), 503–518. https://doi.org/10.1002/icd.475.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. (I). *Psychological Review, 8*, 247–261.

Toepoel, V., Vermeeren, B., & Metin, B. (2019). Smileys, stars, hearts, buttons, tiles or grids: Influence of response format on substantive response, questionnaire experience and response time. *Bulletin of Sociological Methodology, 142*(1), 57–74. https://doi.org/10.1177/0759106319834665.

Tomporowski, P. D., McCullick, B., Pendleton, D. M., & Pesce, C. (2015). Exercise and children's cognition: The role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science, 4*(1), 47–55. https://doi.org/10.1016/j.jshs.2014.09.003.

Tomporowski, P. D., McCullick, B., & Pesce, C. (2015). *Enhancing children's cognition with physical activity games.* Champaign, IL: Human Kinetics.

Tomporowski, P. D., & Pesce, C. (2019). Exercise, sports, and performance arts benefit cognition via a common process. *Psychological Bulletin, 145*(9), 929–951. https://doi.org/10.1037/bul0000200.

Toumpaniari, K., Loyens, S., Mavilidi, M. F., & Paas, F. (2015). Preschool children's foreign language vocabulary learning by embodying words through physical activity and gesturing. *Educational Psychology Review, 27*(3), 445–456. https://doi.org/10.1007/s10648-015-9316-4.

Traverso, L., Viterbori, P., & Usai, M. C. (2015). Improving executive function in childhood: Evaluation of a training intervention for 5-year-old children. *Frontiers in Psychology, 6*, 525. https://doi.org/10.3389/fpsyg.2015.00525.

Traverso, L., Viterbori, P., & Usai, M. C. (2019). Effectiveness of an executive function training in Italian preschool educational services and far transfer effects to pre-academic skills. *Frontiers in Psychology, 10*, 2053. https://doi.org/10.3389/fpsyg.2019.02053.

Twisk, J., Bosman, L., Hoekstra, T., Rijnhart, J., Welten, M., & Heymans, M. (2018). Different ways to estimate treatment effects in randomised controlled trials. *Contemporary Clinical Trials Communications, 10*, 80–85. https://doi.org/10.1016/j.conctc.2018.03.008.

Van der Niet, A. G., Smith, J., Oosterlaan, J., Scherder, E. J., Hartman, E., & Visscher, C. (2016). Effects of a cognitively demanding aerobic intervention during recess on children's physical fitness and executive functioning. *Pediatric Exercise Science, 28*(1), 64–70. https://doi.org/10.1123/pes.2015-0084.

Vazou, S., Pesce, C., Lakes, K., & Smiley-Oyen, A. (2019). More than one road leads to Rome: A narrative review and meta-analysis of physical activity intervention effects on cognition in youth. *International Journal of Sport and Exercise Psychology, 17*(2), 153–178. https://doi.org/10.1080/1612197X.2016.1223423.

Viterbori, P., Usai, M. C., Traverso, L., & de Franchis, V. (2015). How preschool executive functioning predicts several aspects of math achievement in Grades 1 and 3: A longitudinal study. *Journal of Experimental Child Psychology, 140*, 38–55. https://doi.org/10.1016/j.jecp.2015.06.014.

Weng, T. B., Pierce, G. L., Darling, W. G., Falk, D., Magnotta, V. A., & Voss, M. W. (2017). The acute effects of aerobic exercise on the functional connectivity of human brain networks. *Brain Plasticity, 2*(2), 171–190.

Wolfe, C. D., & Bell, M. A. (2004). Working memory and inhibitory control in early childhood: Contributions from physiology, temperament, and language. *Developmental Psychobiology, 44*(1), 68–83. https://doi.org/10.1002/dev.10152.

World Health Organization (2018). Physical activity. Geneva, Switzerland. Retrieved July 13, 2018 from: http://www.who.int/news-room/fact-sheets/detail/physical-activity.

Xue, Y., Yang, Y., & Huang, T. (2019). Effects of chronic exercise interventions on executive function among children and adolescents: A systematic review with meta-analysis. *British Journal of Sports Medicine, 53*(22), 1397–1404. https://doi.org/10.1136/bjsports-2018-099825.

Zelazo, P. D. (2006). The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children. *Nature Protocols, 1*(1), 297–301. https://doi.org/10.1038/nprot.2006.46.