A 30-Minute Physical Education Program Improves Students' Executive Attention

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ABSTRACT— Physical activity is not only beneficial to physical health but also to cognitive functions. In particular, executive functions that are closely related to learning achievement can be improved by acute and recurring physical activity. We examined the effects of a single 30-min physical education program in contrast to a 5-min movement break on working memory, cognitive flexibility, and inhibition of attention and behavioral tendencies of eighty-one 13- to 14-year-old students in grade 7 in Germany. Results indicate that the maintenance of on-task attention in the face of distraction was improved by an aerobic endurance exercise-based physical education program but not by a short aerobic movement break. This suggests that the duration of a school sports program is decisive for improving students' executive attention.

Regular physical exercise improves cognitive functions throughout the life span (Colcombe & Kramer, 2003; Hillman, Erickson, & Kramer, 2008; Ratey, 2008). In particular, executive functions (EFs) that are highly important for learning achievement can be improved by physical activity. Because exercise interventions in early childhood programs and schools can be effective in enhancing school readiness and academic success through their influence on EFs (Blair & Diamond, 2008), it is important to study possible beneficial effects of school sports programs in this age groups.

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Executive Functions and Learning Achievement

EFs are of major importance for learning achievement in content areas such as language, mathematics, and science throughout the school years (Diamond, Barnett, Thomas, & Munro, 2007; Mazzocco & Kover, 2007; St. Clair-Thompson & Gathercole, 2006). Furthermore, students' competence on problem-solving tasks relies on EFs (Kane & Engle, 2002). The executive system organizes strategies for solving problems as well as learning processes. It is of importance for judgment, planning, decision-making, structuring and realizing tasks, and for recognizing and correcting errors (Baddeley & Della Salla, 2003; Carlson, 2003; Roberts, 2003). Students' ability to organize, remember, and apply their knowledge and to manage their time, materials, information, and ideas therefore depends on EFs (Meltzer, 2007; Newhall, 2007). The EFs that have been analyzed in this project are primarily related to working memory, cognitive flexibility, and the inhibition of attention and behavior.

Working memory stores about seven elements (such as words, objects, and numbers) for only a few seconds. Moreover, working memory allows operating with short-term stored information. This is the precondition for the development of complex cognitive functions, including language. We use working memory, for example, when we speak or understand a sentence with an inserted subordinate clause, even if it is a rather long clause and evasive of the subject, especially in the German language, on which Mark Twain famously lamented, without one struggles not to forget the rest said before (Spitzer, 2002). Working memory is also needed to retrieve long-term stored information. Behavior is thus not only induced by current but also by (reactions to) earlier information. A functioning working memory is therefore a precondition for goal-directed behavior.

Inhibition is a further important EF that supports flexible behavior by delaying or even preventing superior responses. Inhibitory control of attention supports therefore selective, focused, and sustained attention (Diamond et al., 2007). The ability to inhibit certain behavior and attention in the face of distraction prevents activities which are in conflict with a certain goal or the current situation. Furthermore, executive control is most needed in situations that involve planning and decision-making, and in overcoming habitual actions (Fan et al., 2009). For students with well-developed inhibitory control processes and therefore better self-regulation and self-discipline, it is easier to initiate learning for an examination instead of watching TV or to listen carefully to what the teacher is saying even when the student's neighboring peers become increasingly restless. Furthermore, it is assumed that effortful control regulates aggression indirectly by controlling reactive tendencies underlying negative affectivity (Posner & Rothbart, 2007). The successful control of behavior therefore correlates negatively with aggression and positively with empathy (Carlson, 2003; Rothbart & Posner, 2001). In physical education (PE), for instance, students with high self-regulatory skills are much less willing to foul teammates in order to reach a victory. Self-regulation that supports positive and suppresses disruptive emotions (Blair & Diamond, 2008) is an important key to success in life (Baumeister & Vohs, 2004), and successful goal-directed and self-regulated behavior enables students to put their knowledge to appropriate use (Newhall, 2007). An additional element of EFs is cognitive flexibility that is based on inhibition and working memory. Cognitive flexibility is the ability to react on altering conditions and demands. Cognitive flexibility supports the taking up of different perspectives respectively to switch between different perspectives, and therefore to think and react in a flexible way (Diamond et al., 2007).

Executive Functions and Cognitive Training

EFs can be improved by cognitive training even in young children, whereby a general training procedure could be more effective than a specific practice procedure (Dowsett & Livesey, 2000). For example, cognitive training in preschoolers of lower income families using the Tools of the Mind curriculum (Bodrova & Leong, 2007), which includes different techniques for supporting, training, and challenging EFs (e.g., using private speech to regulate oneself or during rule-switching, or in mature, dramatic play), is beneficial to EFs like inhibition, cognitive flexibility, and working memory. This in further consequence improves children's school readiness (Barnett et al., 2008; Diamond et al., 2007) and academic achievement (Blair & Diamond, 2008). In addition, there is a dosage-dependent effect of working memory training on fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). Research findings indicate that even in 3- to 5-year-old children inhibitory control aspects of EFs are a prominent correlate of both early mathematics and reading ability (Blair & Razza, 2007). Therefore, children of lower mathematical ability have difficulties in dealing with tasks that measure inhibition of prepotent information and learned strategies, and also show a working memory deficit (Bull & Scerif, 2001). Moreover, children of higher mathematics ability achieve a higher counting span. Counting span also involves working memory as well as inhibition of previous information held in working memory (Bull & Scerif, 2001). To sum up, school readiness and learning achievement across the content areas and grades rely on EF processes, which is why EF skills should be promoted and trained in early childhood programs and schools. Along with cognitive training, physical activity seems to have a positive effect on EFs.

Executive Functions and Physical Activity

EFs can be improved by acute and chronic physical activity (especially aerobic endurance exercise) in populations of depressive patients (Kubesch et al., 2003), in healthy old (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004; Kramer et al., 1999) and young adults (Themanson & Hillman, 2006) as well as in preadolescents and adolescents (Hillman, Castelli, & Buck, 2005; Hillman, Kramer, Belopolsky, & Smith, 2006; Stroth et al., 2009). In particular, high cardiorespiratory fitness is positively associated with behavioral and neuroelectric indices of EFs in adults and children (Hillman et al., 2005; Themanson & Hillman, 2006).

In a further recent study funded by the German Federal Ministry of Education and Research, we investigated underlying mechanisms of beneficial effects of cardiorespiratory fitness and an acute bout of 20-min aerobic endurance exercise in healthy students. Behavioral and neuroelectric indices of response inhibition were assessed by event-related potentials in a Go/No Go paradigm in combination with an Eriksen Flanker Task after a moderate 20-min aerobic endurance exercise and a period of rest, respectively. Twenty higher and lower fit students in grade 7 participated in a controlled cross-over study design. Results show that higher fit students show significantly greater contingent negative variation amplitudes, reflecting increased task preparation processes, as well as decreased amplitudes in N2, reflecting more efficient executive control (Stroth et al., 2009).

One possible mechanism for improving EFs by physical activity could be based on changes in brain chemistry. EFs are influenced by transmitter systems such as dopamine and serotonin. A reduction of dopamine concentration in the dorsolateral prefrontal cortex, for example, has a negative effect on working memory as well as on inhibitory control processes (Diamond, Briand, Fossella, & Gehlbach, 2004). There is also evidence that the serotonergic system is also involved in EFs, in part by influencing the activity of the dopaminergic system (Reuter, Ott, Vaitl, & Henning, 2007). Animal studies show, for instance, that brain serotonin depletion impairs working memory (Hritcu, Clicinschi, & Nabeshima, 2007). In addition, patients with suicidal behavior that is connected to a decrease in serotonergic neurotransmission also show significant deficits in working memory, inhibition, and attention (Raust et al., 2007).

Physical activity influences central dopaminergic and serotonergic systems. Aerobic endurance exercise, when carried out for approximately half an hour and longer leads, first, to a lipolysis-elicted increase in blood-free tryptophan (albumin solubilized from tryptophan and will be bound to the endurance exercise-induced increased free fatty acids) and therefore resulting in a decrease in albumin-bound tryptophan in animals and humans. This increase in blood amounts of free tryptophan directly leads, second, to a higher amount of free tryptophan uptake into the brain (because only free tryptophan can cross the blood–brain barrier). The increased concentration of free tryptophan will cause, third, an increase in serotonin biosynthesis that finally can lead to, fourth, an increase in serotonin release in the brain (Chaouloff, 1997; Strüder & Weicker, 2001). The enhanced serotonin biosynthesis is furthermore caused by an increased muscle uptake of the essential amino acids leucine, isoleucine, and valine during recovery after endurance exercise, thereby decreasing the competitors for free tryptophan at active carrier sites for crossing the blood–brain barrier (Chaouloff, 1997). This acute exercise-induced serotonin biosynthesis may have an effect on EFs that rely on 5-HT-dependent structures. Moreover, animal studies demonstrate that voluntary physical activity also leads to a dopamine increase in the prefrontal cortex (and in further brain areas; Meeusen et al., 2001). The increased tyrosine hydroxylase in the nucleus caudatus (Morgan, Yamamoto, & Freed, 1984), which is of importance for cognitive functions (Ghez & Gordon, 1996), starts only 3 min after the beginning of movement and reaches its peak level within the first 20 min of exercise. Especially with regards to a possible increase of serotonin and dopamine release in the brain after aerobic endurance exercise, we hypothesized more effects on EF processes induced by the 30-min PE program compared with the 5-min movement break (MB), because a 5-min aerobic endurance exercise is too short to lead to an increase of free fatty acids and therefore to an increased serotonin biosynthesis.

Indeed, studying the effects and benefits of physical activity and physical performance in students is a promising research area because school and therefore PE are mandatory for students. Furthermore, because EFs are of major importance for students' learning achievement, it is essential to clarify to what extent EFs can be improved by school sports programs of different duration and intensity. Today, compared with other school subjects, PE is still given a low level of attention especially with regard to the promotion of academic achievement. In addition, in many schools in Germany there is a trend to decrease in PE lessons and to compensate by increasing the number of shorter MBs. These MBs are often of low intensity, which seems to have fewer effects on students' physical fitness, physical and cognitive health, and cognitive functions. Therefore, we investigated in four research schools at the Transfer Center of Neuroscience and Learning at Ulm University the effects of a 30-min PE program and a 5-min MB on working memory, cognitive flexibility, inhibitory attention, and behavioral control processes of grade 7 students.

METHOD

Participants

Eighty-one healthy right-handed students (40 girls) in grade 7 (age range: 13–14 years) with no history of neurological or psychiatric disorders participated in this study. The students came from two German secondary school types (43 from Realschule, and 38 from Gymnasium). One class from each school type (36 students, 15 girls) took part exclusively in the investigation of the effects of a short MB. One other class from each school type (45 students, 19 girls) took part exclusively in the investigation of the effects of the 30-min PE program. Students who were not allowed to take part in PE for reasons of health were not allowed to participate in the study. Students without parental consent were excluded as well. Initially, the study was described to students, teachers, and the principals of schools. Both student and parental consent were obtained through a letter sent to the students' homes. Furthermore, within the classroom as well as within parent–teacher meetings, questions on all aspects of the study were answered. The project was approved by the local ethics committee and was in accordance with the Declaration of Helsinki. Data were gathered between January and May 2007.

The Treatment Conditions

Two different exercise programs were standardized for the study. The PE program consisted of a 30-min predominantly aerobic endurance exercise session. This treatment condition was executed by the PE teachers and was focused on exercise intensity of students' individual performance. In the control condition, students were listening to a 30-min audio book. The MB was also an aerobic endurance exercise session but with a duration of only 5 min. In the control condition, students watched the other students taking part in the 5-min MB. Initially, the teachers were introduced in the PE program and in the MB program.

Physical Education Intervention

The PE program was taught by a PE teacher. The teacher was requested to confirm that the exercise session lasted 30 min. When the program was too short, the teacher had to integrate further exercises. When the program exceeded 30 min, the program had to be reduced. Sports equipments consisted of three long benches. At the beginning, they stood across at a distance so that they could be run over in a five-step rhythm. After a warm-up period of about 5 min, students were organized into two teams. The two teams ran in different ways over the benches for about 10 min (e.g., regular running over the benches, lifting the free leg, jumping with closed legs) followed by invigoration exercises (for abdominal muscles and back extension) at the benches for about 5 min. For the last 10 min, the benches were placed lengthwise. Students repeated the various runs over the benches (e.g., simple running, running zigzag over the benches with three contacts, changing between straddle jump and closed jump, etc.).

Movement Break Intervention

Within the MB, students participated virtually in the "Berlin marathon." Movement instructions were given by their teacher. Before the "marathon" started, a short warm-up was given. During the "race," students and their teacher jogged on the spot while executing different motions such as shadow boxing, bringing up the knees while running, and imitating waving to the audience. The MB ended after 5 min with a cooling-down with different stretching exercises.

Study Design

The study was performed as a randomized within-subject cross-over design. In the first week, students received an introduction to the computerized tasks to measure EFs. On the next day, participants were randomly assigned to the sports condition or to the control condition (a rest of similar duration). During the day, EFs were measured three times: Before and after the respective treatment and control condition, and after the following lesson in mathematics. One week later, on the same weekday and at the same time, the students received the alternative condition. Students who participated in the first week in the sports condition (PE or MB) therefore participated in the second week in the control condition and vice versa. Thus, each student was investigated within a 2-week interval on the same day of the week and during the same lessons to avoid differences in preceding activities or circadian distortions.

Measures

Neuropsychological Tests

To assess cognitive functions that are known to heavily recruit the lateral prefrontal cortex, we implemented computerized versions of a flanker (Rafal et al., 1996) and a dots task (Davidson, Amso, Anderson, & Diamond, 2006). The flanker task was selected to measure the ability to inhibit attention to a stimulus-related affinity to interference (a set of processes that guide the selection of environmental objects as triggers of or targets for action). Furthermore, some working memory is needed to store the rules of the test (Kubesch et al., 2003). The dots task consists of three parts: (a) a congruent, (b) an incongruent, and (c) a mixed condition. The congruent condition, where students had to press on the same side as the stimulus, requires only simple reaction time. In the incongruent condition, where participants had to press a key on the opposite side as the stimulus, inhibitory control of behavior but little working memory is needed. In the mixed condition of the dots task, students must hold two rules in mind to respond either on the same or on the opposite side of the stimulus. This task condition demands working memory, inhibitory control, and cognitive flexibility because students had to switch between the two rules. The mixed condition, therefore, is hypothesized to stimulate the dorsolateral prefrontal cortex to a greater extent than the congruent and the incongruent task conditions (Diamond et al., 2004).

Statistical Analysis

Reaction time data were considered to be the relevant dependent variables in the EF measures. The speed in these tasks is considered to be more informative regarding the quality of information processing than the accuracy in these tasks. Accuracy data hardly differ for adolescents and older individuals compared with young children (Diamond et al., 2007). The median of the reaction time was computed for every student in every condition and at every time. A one-sided Grubbs test for outlying observations was performed on the data to identify extremely high reaction times that possibly mark invalid measurements resulting from a lack of compliance. There was a set of six measurement points (two conditions × three times) for each student.

For the PE condition (Table 1), the flanker task yielded datasets of 42 participants. One participant was marked as an outlier with extremely slow reaction times. This participant was excluded from the data. Three missing data points (0.6%) were replaced with means of the group under the same condition and time. The dots task yielded datasets of 43 participants for the PE condition. Four participants were marked as outliers with extremely slow reaction times and excluded from further analyses. There were no missing data points that had to be replaced.

For the MB condition (Table 2), the flanker test yielded datasets of 28 participants for the MB condition. One participant was marked as an outlier with extremely slow reaction times for all data points. This participant was excluded from further analyses. Seven missing data points (2.2%) were replaced with means of the group under the same condition and time. The dots task yielded datasets of 32 participants for the MB condition. Four participants were marked as outliers with extremely slow reaction times at one data point. Because of the small size of the sample, the participants were not excluded from further analyses, but the data points in question (0.7%) were replaced with means from

Table 1
Reaction Time Analysis of Variance for Physical Education Intervention

Physical education program	N	Intervention condition M (SD)			Control condition M (SD)			Interaction treatment × time	
		Pre	Post	Diff	Pre	Post	Diff	F	p
Flanker task									
Congruent	41	501.6 (70.6)	481.7 (68.8)	19.9 (51.1)	507.8 (70.1)	501.9 (71.6)	5.9 (38.8)	1.79	.188
Incongruent	41	519.4 (69.5)	490.1 (70.6)	29.3 (51.2)	514.5 (72.0)	510.6 (69.7)	3.9 (45.1)	5.90	.020
Dots task									
Congruent	39	329.8 (47.1)	304.0 (35.6)	25.7 (32.6)	325.7 (34.6)	312.1 (33.5)	13.7 (29.0)	2.88	.098
Incongruent	39	363.8 (59.5)	337.3 (41.1)	26.5 (38.3)	353.9 (43.4)	334.3 (38.5)	19.7 (35.8)	<1	.402
Mixed	39	515.7 (78.0)	481.5 (79.2)	34.2 (47.8)	518.4 (81.2)	494.6 (72.9)	23.8 (55.3)	1.07	.307

Table 2
Reaction Time Analysis of Variance for Movement Break Intervention

Movement break	N	Intervention condition M (SD)			Control condition M (SD)			Interaction treatment × time	
		Pre	Post	Diff	Pre	Post	Diff	F	p
Flanker task									
Congruent	27	499.5 (65.3)	497.4 (56.6)	2.1 (49.3)	509.1 (70.2)	509.2 (74.4)	−0.1 (58.6)	<1	.865
Incongruent	27	508.3 (62.2)	505.3 (60.1)	3.0 (58.7)	517.5 (63.7)	514.3 (71.0)	3.2 (36.3)	<1	.988
Dots task									
Congruent	32	331.4 (30.4)	311.7 (29.0)	19.7 (31.7)	319.3 (36.4)	313.7 (31.3)	5.6 (26.2)	3.24	.081
Incongruent	32	358.7 (33.4)	350.5 (32.3)	8.1 (27.7)	351.0 (40.4)	349.4 (40.6)	1.6 (30.6)	1.17	.287
Mixed	32	519.7 (75.3)	501.4 (57.0)	18.2 (52.3)	508.8 (83.0)	488.0 (84.7)	20.7 (63.4)	<1	.862

the group under the same condition and time. There were no missing data points that had to be replaced.

Analysis of variance was computed for reaction time with two repeated measurement factors (time [pre versus post] and treatment [physical exercise versus listening to an audio book or MB versus watching the MB]). To avoid an increase of the likelihood of type I errors, subordinate analyses as well as post hoc contrasts were computed only if superordinate analyses showed significant main effects or interactions. If an interaction effect was found that marked an effect of the intervention, it was tested if the effect lasted until the follow-up measurement. In this case, a paired t-test was used to determine if there was still a difference between the control and the intervention condition at follow-up.

RESULTS

Flanker Task

Thirty-Minute Intervention Versus Rest Condition

The general linear analysis showed a significant interaction effect of treatment and time for the incongruent, $F(1, 40) = 5.90$, $p = .020$ (Figure 1) but not for the congruent condition of the flanker task, $F(1, 40) = 1.79$, $p = .188$. Post hoc analyses showed faster reaction times for the incongruent condition after the 30-min intervention in comparison with both treatment baseline measures (Table 1; post hoc contrasts: $p < .05$).

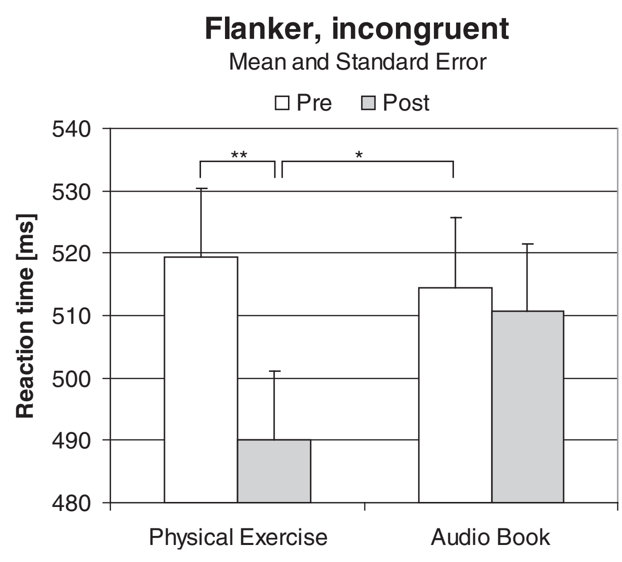

Fig. 1. Mean reaction time in the incongruent condition of the flanker task before and after the physical education activity and the control condition (audio book).

However, the effect of the 30-min intervention on the reaction time in the incongruent flanker condition could not be shown after the lesson in mathematics. In a follow-up measurement, the reaction times for the 30-min intervention (*M*, 507.7; *SD*, 77.7) and listening to an audio book (*M*, 499.6; *SD*, 65.4) did not differ significantly ($t[40] < 1, p = .41$).

Five-Minute Intervention Versus Rest Condition

The general linear analysis showed no significant interaction effect of treatment and time for the congruent, $F(1, 26) < 1$, $p = .865$, nor for the incongruent condition of the flanker task, $F(1, 26) < 1, p = .988$.

Dots Task

Thirty-Minute Intervention Versus Rest Condition

The general linear analysis showed no significant interaction effect of treatment and time for the congruent condition, $F(1, 38) = 2.88$, $p = .098$, the incongruent condition, $F(1, 38) = 0.72$, $p = .402$, or the mixed condition, $F(1, 38) = 1.07, p = .307$.

Five-Minute Intervention Versus Rest Condition

The general linear analysis showed no significant interaction effect of treatment and time for the congruent condition, $F(1, 31) = 3.24, p = .081$, the incongruent condition, $F(1, 31) = 1.17, p = .287$, or the mixed condition, $F(1, 31) < 1, p = .862$.

DISCUSSION

For many education policy makers, principals, teachers, and parents—in the United States as well as in Germany and other European countries—PE, in comparison with subjects such as mathematics, language, and natural sciences, is of dangerously low importance. However, PE trains not only the body (which in itself is of great importance) but also the mind (Hillman et al., 2008; Ratey, 2008).

In our study, we showed that a single PE program of 30 min leads to an improvement in the maintenance of on-task attention in the face of distraction. This in turn may support students' selective, sustained, and focused attention processes (Diamond et al., 2007). This improvement could be found in German students in middle and higher secondary schools. However, improved ability to inhibit attention to distraction was not achieved by a 5-min MB. Therefore, the duration of the sports program seems to be crucial for the measured improvement in inhibitory attention processes.

Working memory, cognitive flexibility, and inhibition of behavioral tendency, which were measured with the dots task, were neither influenced by the 30-min sports intervention nor by the 5-min MB intervention. We therefore hypothesize that test duration may also be decisive because we only found effects in the flanker but not in the dots task. While the flanker task consisted of 55 trials per condition, the dots task had only 30 trials per condition. In further studies, we will therefore increase the number of trials in the dots task.

We further suggest that a possible increased synthesis of serotonin after the 30-min PE program may directly lead to an increased serotonergic tone and consequently to the improvement in the incongruent condition of the flanker task. Study results suggest that a serotonergic modulation in the prefrontal cortex occurs simultaneously with decreased impulsivity to increased attentional selectivity (Boulougouris & Tsaltas, 2008).

The slower reaction time in the incongruent condition of the flanker task after the lesson in mathematics—which is, at this point in time, still below the output value before the preceding 30-min PE program—may be related to the depletion of serotonin after an acute bout of endurance exercise. The exercise-induced increase of serotonin has its maximum within the first 10 recreation minutes after exercise. In the following hour, there is a gradual decomposition of brain serotonin compared with the initial value (Hollmann & Strüder, 2001).

Our study results provide arguments for an increase in PE and suggest that PE should be scheduled before important subjects like mathematics and not at the end of the school day, as is often the case. Because students' physical fitness seems to be more relevant than an acute bout of exercise for improving students' EFs (Hillman et al., 2005; Stroth et al., 2009), this further strengthens arguments for more PE because higher fitness could not be achieved with short MBs. Short MBs could have effects on cognitive functions if they include coordinative exercises (of 10 min; Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008) or if they are highly intensive (two sprints of 3 min; Winter et al., 2007). However, if one wants to expose students to high-intensity physical exercise, they should be well trained. This argues again for more, ideally daily, PE lessons (Stroth et al., 2009).

In actuality, only 6% of American high schools offer daily PE classes (Ratey, 2008). At the same time, in the United States and Germany, students spend more than 5 hr per day in front of a television or computer screen (Ratey, 2008; Spitzer, 2005) and therefore have become increasingly unfit. Approximately 30% of German and American students are overweight (Ratey, 2008; Spitzer, 2005). Cuts in PE should be stopped if the goal is to improve students' physical and cognitive health and strengths (Diamond, 2007). PE seems to be an effective way to improve students' executive attention processes and therefore has the potential to support academic achievement across the subject areas and grades. It is worthy of further investigation.

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