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The effect of acute cognitively engaging physical activity breaks on children's executive functions: Too much of a good thing?

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A R T I C L E I N F O

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A B S T R A C T

Objectives: Acute bouts of physical activity may have an impact on children's executive functions. However, the role played by cognitive engagement (CE) during physical activity remains unclear. Therefore, the aim of the study was to disentangle the separate and/or combined effects of physical exertion (PE) and CE, induced by classroom-based physical activity, on children's executive functions.
Design: In a 2 × 2 between-subjects experimental design, 216 children ($M_{age} = 7.94$, $SD = 0.44$, 49.1% girls) were randomly assigned to one of four conditions consisting of a classroom-based physical activity intervention varying in both physical exertion (high PE vs. low PE) and cognitive engagement (high CE vs. low CE).
Methods: Executive functions (updating, inhibition, shifting) were measured before and immediately after a 20-min intervention. To test whether a potential change in children's executive functions was due to the main effect of PE or CE or an interaction of both, three separate ANCOVAs were conducted.
Results: Contrary to the hypotheses, there was a significant, negative effect for the CE factor in shifting. No effects were found in either updating or inhibition. No significant effects were found for either the PE factor or the interaction of PE and CE in any of the executive functions.
Conclusions: The results indicate that an acute bout of CE in classroom-based physical activity may deteriorate children's cognitive performance. These surprising results are discussed in the light of theories predicting both facilitating and deteriorating effects of cognitively engaging physical activity.

1. Introduction

Acute bouts of physical activity seem to promote children's cognitive functions (Chang, Labban, Gapin, & Etnier, 2012). Studies investigating the relationship between acute bouts of physical activity and cognition have focused in particular on quantitative characteristics, such as intensity and/or duration. A variety of durations ranging from 11 to 20 min, and intensities of moderate to vigorous levels, seem to be most effective to enhance various measures of cognitive performance in children (Chang et al., 2012). However, investigations targeting qualitative characteristics (e.g. modality) of physical activities are limited, despite their importance from a practical point of view (Pesce & Ben-Soussan, 2016). To ascertain which specific type of physical activity is the most effective in promoting cognitive functions, studies comparing the effect of different physical activity modalities on cognitive outcomes are required (Vazou, Pesce, Lakes, & Smiley-Oyen, 2016). One qualitative characteristic of physical activity most widely discussed, and which has an impact on children's cognitive functions, is the cognitive demand. Cognitive demands are inherent in many forms of physical activities (Best, 2010), where it is thought to induce cognitive engagement (CE), which is defined as the degree to which cognitive effort is needed to master difficult skills (Tomporowski, McCullick, Pendleton, & Pesce, 2015).

Studies comparing different types of acute physical activities reported varying results. While some studies revealed positive effects on children's and adolescent's cognitive performance in favour of the combined, i.e. cognitively and physically engaging condition (Budde, Voelker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008; Jäger, Schmidt, Conzelmann, & Roebers, 2014; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009), others found larger improvements for those conditions focusing either on PE or CE separately compared to the combined (PE and CE) condition (Gallotta et al., 2012, 2015). Other studies reported no differences in cognitive outcomes comparing cognitively to non-cognitively engaging physical activities (Best, 2012; van den Berg et al., 2016).

The inconsistent findings of those studies manipulating the level of CE in acute physical activity could be explained by procedural differences. Intensities as well as durations vary widely across studies, with

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heart rates ranging from 120 (Budde et al., 2008) to 160 bpm, (Best, 2012) and activity durations ranging from 10 (Budde et al., 2008) to 50 min (Gallotta et al., 2012, 2015). In terms of modality, varying forms of cognitively engaging physical activities (e.g. coordinative exercise, team games, exergaming) were examined using either two or three comparison groups in different settings (e.g. gym, classroom, and laboratory). However, to explore the specific role of CE induced by an acute bout of physical activity, it might be worthwhile to consider those studies which have systematically manipulated both the physical and the cognitive component of physical activity, by means of a 2 × 2 design. While Best (2012) reported a main effect for the physical component only, Jäger, Schmidt, Conzelmann, and Roebers (2015) showed no main effects for either the CE factor or the PE factor in the entire sample. Nevertheless, they reported differential effects, showing more pronounced improvements for children with higher levels in fitness and/or academic achievement, compared to their lower level counterparts. Finally, Schmidt, Benzing and Kamer (2016) showed that CE was the crucial factor in increasing cognitive performance, while the PE factor had no effect on any measure of children's attentional performance. Thus, the variety of results still provide no answer to whether PE, CE, or both in combination, are the most promising in fostering children's cognitive performance.

Besides the aforementioned procedural differences, individual constraints, such as children's age, gender, fitness level or academic achievement, could potentially explain some of the inconsistencies concerning the acute exercise-cognition relationship (Pesce, 2009). While studies examining older children (Budde et al., 2008; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009) generally revealed positive effects, results for younger children mainly showed no beneficial effects through cognitively engaging physical activities (Gallotta et al., 2012, 2015; Jäger et al., 2015). It seems that improving cognitive performance in younger children is more challenging compared to older children, possibly due to an excessive strain induced by both physical and cognitive engagement on young children.

A closer look at the primary cognitive outcomes of these studies reveals that especially executive functions (EFs) seem to profit from acute physical activities (Chang et al., 2012). EFs are known to be crucial for mental and physical health, academic achievement, school readiness and school success (Diamond, 2013). The term "EFs" refers to a set of top-down mental processes that allows for controlled and goal-directed behaviour (Banich, 2009). As suggested by Miyake et al. (2000), EFs can be subdivided into three core dimensions: The first dimension is *updating,* the ability to keep relevant information in working memory. The second dimension, *inhibition*, refers to the avoidance of dominant, automatic or prepotent responses. The third dimension, *shifting,* is based on updating and inhibition, and represents the ability to change among multiple tasks, operations, rules or perspectives. From a developmental perspective inhibition is the first EF to reach full development in children, whereas shifting is the last (Diamond, 2013). In general, children with better EFs seem to have an easier transition to formal schooling, (Blair & Diamond, 2008) and are able to adapt their behaviour in the classroom more appropriately (Riggs, Blair, & Greenberg, 2003). Previous studies targeted on- and off-task behaviour (Grieco, Jowers, & Bartholomew, 2009; Ma, Le Mare, Brendon, & Gurd, 2014) or attention (Best, 2012; Budde et al., 2008; Gallotta et al., 2012, 2015; Schmidt et al., 2016; van den Berg et al., 2016). In terms of the core EFs, updating (Jäger et al., 2015; Pesce et al., 2009), inhibition (Benzing, Heinks, Eggenberger, & Schmidt, 2016; Jäger et al., 2015; Vazou & Smiley-Oyen, 2014) and shifting (Benzing et al., 2016; Jäger et al., 2015) were examined. However, only few studies (Jäger et al., 2014, 2015) included all three core EFs to gain a more thorough understanding in terms of selective changes through physical activity interventions.

Cognitively engaging classroom-based physical activity is gaining attention as a promising tool, to enhance daily physical activity, and to improve not only physical activity levels, but also cognitive functions (e.g. EFs) and academic achievement (Watson et al., 2017). Two different types of classroom-based physical activities can be distinguished: a) integrated physical activity, which incorporates physical activity during academic lessons (e.g. hopping the result of an arithmetic problem) and b) physical activity breaks, which consist of short bouts of physical activity between lessons (e.g. performing coordinative exercises) (Webster, Russ, Vazou, Goh, & Erwin, 2015). Integrated physical activity is cognitively engaging due to the fact that an academic concept is being taught. However, physical activity breaks can be more or less cognitively engaging depending on the specific exercise performed. A closer look at the literature reveals that most of the studies so far focused on chronic, i.e. long-term interventions, and used integrated physical activity (Vazou & Skrade, 2016), while acute, i.e. single bouts of physical activity using physical activity breaks, were less thoroughly investigated.

Evidence for studies focusing specifically on the effects of acute classroom-based physical activity breaks is small and inconsistent findings on cognitive outcomes have been reported. The durations of the investigated physical activity breaks ranged between 5and 20 min. While shorter physical activity breaks (5 min) revealed no cognitive improvements (Howie, Schatz, & Pate, 2015; Kubesch et al., 2009), longer durations (equal to or more than 10 min) showed beneficial effects on cognitive outcomes (Howie, Beets, & Pate, 2014), suggesting that longer interventions seem to have a stronger effect on children's cognitive outcomes. Several types of physical activity breaks have been investigated with either more or less CE inherent in each type. So far, one single study systematically compared a CE to a less CE activity break and showed beneficial effects only in terms of the CE activity break on children's attention (Schmidt et al., 2016). Therefore, challenging physical activity breaks are likely to enhance cognitive functions to a greater degree (Watson et al., 2017). Taken together, one could hypothesize that physical activity breaks that combine physical effort with high cognitive demands are more effective than physical activity breaks with either low cognitive demands or low physical effort.

Given large interindividual differences in physical as well as in personality traits, it seems reasonable to assume that not every child will profit to the same extent, from the same physical activity break. The meta-analysis performed by Chang et al. (2012) supports this claim. Furthermore, three recent experimental studies (Chang et al., 2012; Hogan et al., 2013; Jäger et al., 2015) indicate that participants with higher fitness and/or higher academic achievement seem to benefit more from acute exercises concerning cognitive functions. Thus, age, physical fitness, as well as academic achievement could be potential moderating variables for the effect of acute physical activity breaks on children's EFs.

The two aims of the current study were therefore to test whether (1) PE and CE affects children's EFs separately or in combination and (2) whether all individuals would equally benefit from the same intervention.

2. Materials and methods

2.1. Design

The goal of the study was to address the practical question of what type of physical activity break should be used to improve EFs. Therefore, four different physical activity breaks systematically differing in the level of CE and PE were compared in a 2 × 2 between-subjects design. Children were randomly assigned to one of the four conditions: (a) *Combo group* (high CE, high PE), (b) *Cognition group* (high CE, low PE), (c) *Aerobic group* (low CE, high PE) and (d) *Control group* (low CE, low PE). EFs were measured before (pre-test) and immediately after the intervention (post-test). For each condition, the same tests were completed and conducted at the same time, and in the same order, in unused classrooms. To test the successful manipulation of CE and PE, children's heart rate, perceived physical exertion (RPE) and perceived cognitive engagement (RCE) were assessed. Additionally, children's height, weight, and socioeconomic status were measured after the post-test. Information on the following background variables was gathered independently 2–4 weeks after the intervention: academic achievement, aerobic fitness and gross motor coordination.

2.2. Subjects

A total of $N = 226$ second graders ranging between 7 and 9 years of age ($M_{age} = 7.94$, $SD = 0.44$) from 19 different elementary schools in the region of Bern, Switzerland, were tested. Ten children were identified as multivariate outliers based on the Mahalanobis distance (Fidell & Tabachnick, 2003) greater than 27.877 ($p < .001$, $df = 9$), and were therefore excluded. Due to technical problems with the tablets used to assess EFs, there was some loss of data. Since the MCAR test (Little & Rubin, 2002) has led to a non-significant result (χ^2 (688) = 665.213, $p = .727$), the missing values were imputed using the expectation-maximization (EM) algorithm. The final sample consisted of 216 children (49.1% girls). The participants and their parents/legal guardians provided written informed consent to participate in this study. The Ethics Committee of the Faculty of Human Sciences at the University of Bern confirmed ethical consent for the study. Considering previous studies (Chen, Yan, Yin, Pan, & Chang, 2014; Röthlisberger, Neuenschwander, Cimeli, & Roebers, 2013; Vazou & Smiley-Oyen, 2014), an a-priori power analysis (with 1- beta error probability = .80; alpha error probability = .05; effect size $f = .25$; number of groups = 2; number of covariates = 1) was performed. An optimal sample size of $N = 211$ was calculated. Table 1 provides an overview of the relevant background variables, which did not differ among groups.

2.3. Procedure

Children from the same class were randomly assigned to one out of four conditions. At 09.00 a.m., the first session started, which lasted altogether 80 min. At the beginning of the testing (09.00 a.m.–09.05 a.m.), each participant was fitted with heart rate monitoring equipment and familiarized with the EFs tests on the tablets in advance. An investigator – blinded with respect to participant assignment – monitored the entire cognitive testing. The pre-test lasted between 18 and 22 min (about 09.05 a.m.–09.25 a.m.) and was conducted in a quiet separate room, followed by the experimental conditions (09.25 a.m.–09.50 a.m.; including time for instructions and room change). The intervention itself was carried out by a second investigator in an unused classroom. To minimize confounding effects of elapsed time after the intervention, the post-test (consisting of the same EFs measurement) was carried out immediately after (09.50 a.m.–10.10 a.m.) the treatment. After a short break, the children filled out the questionnaire consisting of relevant background variables (10.10 a.m.–10.20 a.m.). Two of these sessions lasting 80 min were completed in one school, i.e. 8 children could be tested in one morning. The second group of four children started 20 min later and completed the identical procedure. Of course, this delay was counterbalanced across the four experimental conditions. Aerobic fitness, gross motor coordination and academic achievement was assessed independently during a physical education lesson, respectively during a regular school lesson.

2.4. Experimental conditions

Each intervention consisted of three different games, lasting 6 min each, and including short breaks between changing the game. The games itself consisted of the same content for each group, only varying in the amount of PE (high/low) and CE (high/low). For better readability, only the first game is described in more detail below.

(a) *Combo group* (high CE, high PE; $n = 59$). The children had to run while listening several times to the same song lasting two min each round. The song included three special keywords (car, coin, post office), belonging to a certain movement, which was introduced before the song was played. Whenever one of the words was mentioned in the song, the children had to react as quickly as possible with the predefined movement (car = jump up, coin = spin around, post office = sit down). The song was played three times, and in every run, the rules were changed with an increasing level of difficulty. For example, when the children heard the word “car” in the first run, they had to jump up and then keep on running. In the second run, the word “car” was no longer related with “jump up”, but rather with “spin around”. The repetition with additional keywords and changing corresponding movements was crucial in this exercise: The children had to update the new information, inhibit the movements from the previous run which were no longer correct, and shift between the different words and their corresponding new movements.

(b) *Cognition group* (high CE, low PE; $n = 53$). The children sat in a circle and listened to the same aforementioned song. According to the three keywords, the children were instructed to react as quickly

Table 1
Means (standard deviations) and test statistics for background and manipulation check variables by the four experimental groups.

Sample Characteristics	High CE				Low CE				F (3, 212)	p	η_p^2
	Combo group (High PE)		Cognition group (Low PE)		Aerobic group (High PE)		Control group (Low PE)				
	M	SD	M	SD	M	SD	M	SD			
Age	7.99	0.38	7.93	0.45	7.96	0.50	7.90	0.44	0.40	.754	.006
Gender (male/female)	24/35		28/25		32/18		26/28		2.07	.105	.028
SES	7.03	1.50	7.05	1.31	6.54	1.55	6.51	1.60	2.15	.095	.030
BMI (kg/m^2)	16.40	2.54	16.21	3.12	16.56	1.97	15.79	1.77	1.01	.391	.014
Gross motor coordination	107.19	14.70	109.31	14.46	105.75	13.63	103.12	15.45	1.70	.168	.024
Aerobic fitness	304.58	123.18	284.27	141.16	306.43	144.23	278.55	129.13	0.60	.619	.008
Mathematics	50.52	6.01	50.39	7.23	50.95	6.55	48.26	5.91	1.88	.135	.026
Spelling	52.85	8.46	53.06	7.96	54.99	8.39	51.90	7.17	1.35	.260	.019
Reading	20.83	9.48	22.54	9.82	23.42	8.78	19.56	10.36	1.69	.170	.023
Manipulation Check Variables											
Mean HR (bpm)	139.06	15.50	103.24	8.29	143.31	18.39	94.49	14.59	153.71	< .0005	.685
RPE	9.91	3.42	8.32	2.33	10.04	3.10	7.00	1.71	14.96	< .0005	.175
RCE	4.90	2.79	4.60	2.51	2.30	1.91	2.73	2.45	15.28	< .0005	.178

Note. CE: Cognitive engagement. PE: Physical exertion. SES: Socioeconomic status. BMI: Body mass index. HR: Heart rate. RPE: Rating of perceived exertion. RCE: Rating of perceived cognitive engagement.

as possible with their arms and fingers whenever they heard one out of three keywords. For example, when they heard "car" they had to imitate driving a car. When they heard "coin", they formed a circle with their forefinger and thumb. The song was played three times with an increasing level of difficulty (additional keywords and changed corresponding movements). The repetition induced all of the three core EFs.

(c) *Aerobic group* (low CE, high PE; $n = 50$). As in the *combo group*, the children had to run while listening to the same song. The song was also played three times and participants made exactly the same movements (jump up, sit down and so on) whenever they heard the three different keywords. The difference here was that in contrast to the other groups, the investigator acted out the correct movement assigned to each keyword in advance. Therefore, the children only had to imitate the movements without remembering the correct movements relevant to the keywords.

(d) *Control group* (low CE, low PE; $n = 54$). The children sat comfortably in a circle and listened to an age-appropriate audio book for 20 min. To keep the cognitive demands as low as possible, the children were told to sit still and relax and that they would not be tested on the context of the story.

2.5. Background variables

Socioeconomic status. To assess the socioeconomic status (SES), the Family Affluence Scale II (FAS II; Currie et al., 2004) was used. The four questions asked for information about car ownership, bedroom occupancy, computer ownership and holidays. FAS II was constructed as a zero to nine-point scale, whereas the response format varies by item. Evidence of the scale's reliability and validity has been reported by Boudreau and Poulin (2009).

Body mass index. The body mass index (BMI) was calculated with body weight in kilograms divided by height in meters squared.

Mathematics. The children's mathematical capacities were tested with the Heidelberger Rechentest (HRT 1–4; Haffner, Baro, Parzer, & Resch, 2005). Six out of twelve subtests were assessed. The t-scores were calculated, which reflect the deviation of the age-related mean score.

Spelling was assessed with the Hamburger Schreib-Probe (HSP 1–10; May, 2012). As a measure of spelling, the number of correctly used words (i.e. number of correctly spelled words) was calculated. The t-scores were calculated, which reflect the deviation of the age-related mean score.

Reading was assessed with the Salzburger Lesescreening für die Klassenstufen 1–4 (SLS 1–4; Mayringer & Wimmer, 2003). As a measure of reading, the number of correctly given answers was calculated. The t-scores reflect the deviation of age and gender-related mean score. The correlations between the three academic achievement tests were all significant (r between .36 and .44). To test academic achievement as a potential moderator, the z-standardized values of the three tests were aggregated to form a general academic achievement score.

Aerobic fitness. The children's aerobic fitness was measured using the Multistage 20 metre Shuttle Run test (Léger, Mercier, Gadoury, & Lambert, 1988). Evidence of reliability and validity of the 20 metre Shuttle Run test has been provided (Liu, Plowman, & Looney, 1992). The score reflects the duration of running time given in seconds.

Gross motor coordination. Children's gross motor coordination was measured using the Körperkoordinationstest für Kinder (KTK; Kiphard & Schilling, 2007). The children performed the four subtests: a) walking backwards b) moving sideways c) hopping for height and d) jumping sideways. Points were given for each test item to make up the overall motor quotient (MQ) under consideration of gender and age factor. The overall MQ allows an assessment of the gross motor development by considering these categories: MQ 56–70 = severe motor disorder, MQ 71–85 = moderate motor disorder, MQ 86–115 = normal, MQ 116–130 = good, and MQ 131–145 = high. A test-retest reliability of $r = .97$ was reported by Kiphard and Schilling (2007). The correlation between the Körperkoordinationstest and the 20 metre Shuttle Run test was significant ($r = .41$). To test motor performance as a potential moderator, the z-standardized values of both motor tests were aggregated to form a general motor performance score.

2.6. Manipulation check variables

Physical exertion. Heart rate data was collected during the entire test session, using Polar Team[2] straps and transmitters (Polar Electro Oy, Kempele, Finland). In the analyses, only the mean heart rate during the intervention period was used as an objective measure for PE. Additionally, children reported their perceived physical exertion, using the Borg RPE scale (Borg, 1982). Reliability and validity of the Borg scale has been reported by Lamb (1996) to be feasible in pre-adolescents.

Cognitive engagement. To assess the perceived CE during the classroom-based physical activities, the Self-Assessment Manikin (Bradley & Lang, 1994) was adapted to specifically ask for perceived CE. As in the original Self-Assessment Manikin, for example for arousal, here the children had to rate their perceived CE ranging from 1 ("not cognitively engaging at all") to 9 ("very, very cognitively engaging"). The question they had to answer was: "how cognitively engaging was the previous activity for your brain?". Even though the instrument has not been validated, it has been shown to be feasible in adolescents (Benzing, Heinks, Conzelmann, & Schmidt, 2016).

2.7. Dependent variables

The three core EFs were measured by two tablet-based tasks using E-Prime Software (Psychology Software Tools, Pittsburgh, PA). Each task required approximately 10 min, including instructions over headphones. The tasks were counterbalanced.

Updating was assessed by means of a Backward Colour Recall task (Roebers et al., 2014; Roebers, & Kauer, 2009; Schmid, Zoelch, & Roebers, 2008). The task is embedded in a cover story about a dwarf who loses sequences of coloured discs, starting with a two-disc sequence. The discs were presented for 1 s, separated by interstimulus-intervals of 500 ms. The children were asked to recall the sequences in the reverse order (by pressing the correct colour disc on the tablet). The first practice block included 3 trials of a two-disc sequence with a feedback loop whenever 66% of the trials were incorrect. Sequence length was increased by one disc when 50% of the six test trials were correct, otherwise the task was interrupted. The total score of trials recalled correctly was used as the dependent measure. Test-retest reliability for the age group of 4-5-year-olds has been reported by Schmid et al. (2008).

Inhibition was assessed with a child-adapted Eriksen Flanker task (Eriksen, & Eriksen, 1974). The fish Flanker task is considered as the child version of the Attention Network Test (Rueda et al., 2004) and has widely been applied in developmental research (Roebers, & Kauer, 2009; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2011; Rueda, Posner, & Rothbart, 2005) including exercise and cognition studies (Jäger et al., 2014, 2015; Schmidt, Jäger, Egger, Conzelmann, & Roebers, 2015; Schmidt et al., 2017). The task consisted of two different blocks including five practice trials per block and a feedback loop whenever the performance was below 60%. The "pure" block, consisted of 16 congruent trials and the "standard" block consisted of 16 congruent and the same number of incongruent trials, randomly presented. Inter-stimuli-intervals varied randomly from 800 to 1400 ms (Jäger et al., 2014; Roebers, & Kauer, 2009). As a dependent variable for inhibition the conflict score between trials with the highest rate of distraction (incongruent trials in the standard block) and trials with the lowest rate of distraction (congruent trials in the pure block) were calculated (Fatzer, & Roebers, 2012; Rueda et al., 2005).

Shifting was assessed with an additional "mixed" block within the

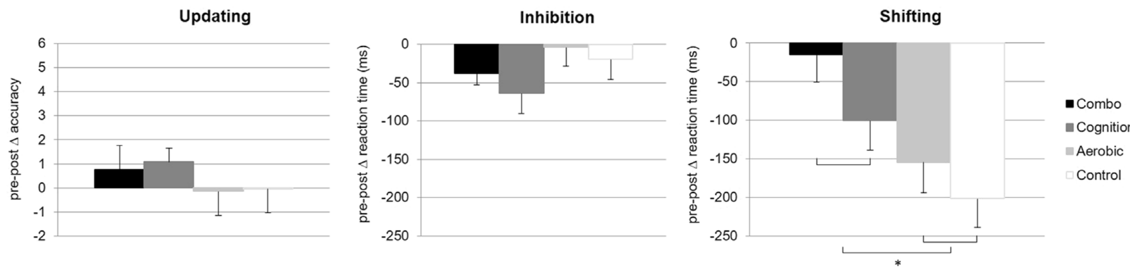

Fig. 1. Means and error bars (representing the standard error of the mean) for the change (Δ) in the three core EFs (updating, inhibition, and shifting) in the four experimental conditions between pre- and post-test. $^{*}p < .05$.

Flanker task. A new rule, cued by a different colour of the trials, was introduced. Children had to adapt their response relating to the colour. Whenever the colour of the trails changed, a switch between the two rules was claimed. A total of 16 congruent and the same number of incongruent trials were randomly presented. Inter-stimuli-intervals varied randomly from 800 to 1400 ms (Jäger et al., 2014; Roebers, & Kauer, 2009). As a dependent variable for shifting, the global switch costs were calculated (Chevalier, & Blaye, 2009). The difference between the mixed block and the standard block was calculated. Hence the inhibition components within the "mixed" block were controlled (trials in the mixed block not only required shifting between different tasks but also involve inhibitory demands).

2.8. Statistical analysis

All statistical analyses were performed using SPSS 23.0 (SPSS Inc., Chicago, IL, USA). Preliminary analyses were conducted using ANOVAs for between-group comparisons of background variables (socio-economic status, body mass index, mathematics, spelling, reading, aerobic fitness, and gross motor coordination). At pre-test, no significant differences were observed (see Table 1).

Manipulation check variables (mean heart rate, perceived PE and perceived CE) were tested using three separate ANOVAs. Bonferroni-corrected post-hoc comparisons were used to determine differences between groups. To test whether a potential change in children's EFs is due to a main effect of PE and CE or to interaction (PE x CE), three separate ANCOVAs were conducted, with the three core EFs (updating, inhibition, shifting) as dependent variables. To control for potential baseline imbalances, pre-test measures of the dependent variables were used as covariates (Vickers & Altman, 2001). In the outlier analyses, trials with a reaction time under 150 ms were excluded. In a next step, trials with reaction times deviating by more than 3 *SD* from the child's mean were excluded as well. Only correct trials were included in the calculation of reaction times (Salthouse, & Hedden, 2002). Further, blocks (see dependent variables for a description) with an accuracy below 50% were deleted because those children seemed either to have not understood the block in a task or to have done it incorrectly due to a lack of motivation. Because of the expected ceiling effect concerning accuracy in the Flanker task (mean accuracy between 87% and 94%), for inhibition and shifting only reaction times were used in the subsequent analyses. Updating is given in accuracy. To test the moderating effect of age, gender, motor performance and academic achievement, four separate ANCOVAs were conducted. The level of significance was set at $p < .05$ for all analyses and partial eta square (η_p^2) was reported as an estimate of effect size.

3. Results

3.1. Manipulation check

The manipulation check analyses revealed significant differences in heart rate, rates of perceived physical exertion and ratings of perceived cognitive engagement (see Table 1). Higher heart rates (F (1, 214) = 429.40, $p < .0005$, $\eta_p^2 = .667$) as well as higher ratings of perceived physical exertion (F (1, 214) = 37.91, $p < .0005$, $\eta_p^2 = .150$) were observed in the two high PE conditions compared to the two low PE conditions. The intensity of the high PE conditions elicited 67% of the maximal heart rate using the formula 220 - age (Fox, Naughton, & Haskell, 1971), indicating that the high PE conditions elicited moderate to vigorous-intensity. The mean heart rate of the low PE conditions corresponded to 47% of the maximum heart rate. Considering perceived CE, the two high CE conditions required more effort (F (1, 214) = 44.80, $p < .0005$, $\eta_p^2 = .173$) than the low CE conditions. Overall, the results indicate a successful experimental manipulation.

3.2. Main analyses

To examine whether PE and CE affect children's core EFs (updating, inhibition, shifting) separately or in combination, three separate ANCOVAs were performed. The results revealed a lower shifting performance (F (4, 211) = 7.76, $p = .006$, $\eta_p^2 = .035$) for the children in the high CE conditions compared to the low CE conditions (see Fig. 1). No significant effects were found either for updating (F (4, 211) = 2.53, $p = .113$, $\eta_p^2 = .012$) or for inhibition (F (4, 211) = 1.50, $p = .222$, $\eta_p^2 = .007$). For the PE factor, no significant effects were observed in any of the three core EFs or the interaction of CE and PE ($ps > .05$). Descriptive statistics of the dependent variables are presented in Table 2.

To test the moderating effect of age, gender, motor performance and academic achievement, children were divided into a lower and higher group ($n_{high} = 108$; $n_{low} = 108$) by four median splits separately for girls and boys. Interestingly, none of the four moderating variables had a significant main effect of the factors CE ($ps > .095$) and PE ($ps > .276$) or interaction effect ($ps > .197$) on the three dependent variables.

4. Discussion

The aim of the study was to examine to what extent the three core EFs can be influenced by the factors of PE and CE, both systematically manipulated, using four different interventions of classroom-based physical activity breaks. It was hypothesized that a combination of CE and PE of acute physical activity breaks would have a stronger impact on children's EFs than CE or PE alone. Surprisingly, the results did not confirm this hypothesis, since only the factor CE affected children's shifting performance, with the revealed effect pointing towards a deterioration. The core EFs, updating and inhibition remained unaffected. Since no main effect was found for either the PE condition, or the interaction between PE and CE, it seems unlikely that the increased physical arousal alone is responsible for the effect. The current results contradict previous research showing larger improvements in EFs through acute cognitively engaging physical activity interventions in general (Benzing et al., 2016; Budde et al., 2008; Pesce et al., 2009), but also in classroom-based settings, (e.g. Vazou and Smiley-Oyen, 2014)

Table 2
Means, standard deviations, for the three core EFs at pre- and post-test for the four conditions and test-statistics for the pre-test.

	High CE				Low CE				F (4, 211)	p	η_p^2
	Combo group (High PE)		Cognition group (Low PE)		Aerobic group (High PE)		Control group (Low PE)				
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*			
Updating[a]											
Pre-test	3.15	0.41	3.19	0.45	3.25	0.43	3.31	0.67	1.12	.343	.016
Post-test	3.31	0.51	3.36	0.63	3.29	0.49	3.22	0.46			
Inhibition[b]											
Pre-test	169.93	158.50	169.93	149.47	158.22	195.49	141.05	168.31	0.36	.781	.005
Post-test	132.21	138.04	106.00	138.51	154.13	153.53	121.30	138.67			
Shifting[b]											
Pre-test	460.55	296.60	526.94	298.06	503.18	364.35	639.28	365.97	2.93	.035	.040
Post-test	445.93	217.97	426.63	250.13	348.42	235.25	437.75	230.31			

Note. CE: Cognitive engagement. PE: Physical exertion.
[a] Accuracy corresponds to the number of correct responses.
[b] Reaction time is given in milliseconds.

and therefore need to be discussed.

4.1. The inverse effect of cognitive engagement

The CE factor was identified as having a different effect as hypothesized on children's reaction time in shifting performance. Thus, cognitively challenging activity breaks, regardless of whether they are physically exerting or not, seem to lead to a lower shifting performance compared to cognitively low-demanding active or sedentary breaks. In the interest of full disclosure, the low CE conditions (aerobic and control group) showed slightly lower shifting performance at pre-test, and had therefore more room for improvement at the post-test. However, the conducted ANCOVA adjusts each child's post-test score for his or her baseline score making them unaffected by baseline differences.

Compared with other studies investigating the effect of acute bouts of cognitively engaging physical activity, the results might be explained by a (too) long physical activity break (20 min) with second graders. So far, most studies showing positive effects of CE physical activities used durations between 10 and 15 min (e.g. Benzing et al., 2016; Budde et al., 2008; Schmidt et al., 2016; Vazou & Smiley-Oyen, 2014). Only van den Berg et al. (2016) could not find a positive effect on cognitive functions after a 12-min classroom-based exercise session. The upper time limit of 15 min seems to be in line with the findings by Howie et al. (2014) who investigated the dose-response relationship in fourth and fifth graders. Whilst a duration of 10 min showed positive effects on academic outcomes, no significant effect was found for neither shorter (5 min) nor longer durations (20 min). Another cognitively challenging intervention lasting 50 min led to a lower cognitive improvement compared to a physical activity without CE (Gallotta et al., 2012, 2015). Considering all this, the results suggest a curvilinear relationship between physical activity durations and its cognitive effects. Neither a too short nor a too long duration seems to lead to an optimal cognitive performance in children. Chang et al. (2012) reported in their meta-analysis the moderating role of duration, where results showed that a duration between 11 and 20 min enhances cognitive functions (compared to shorter or longer durations) to the highest degree. These findings are probably not applicable to younger children, and may not be valid for classroom-based physical activity breaks including high amounts of CE.

Besides task constraints, such as exercise duration or intensity, individual constraints need to be discussed as a potential explanation for the current results. Whereas previous studies showed mainly positive effects of older children (Budde et al., 2008; Pesce et al., 2009), positive effects on cognitive functions seem much harder to obtain in younger children (Gallotta et al., 2012, 2015; Jäger et al., 2015). Hence, the current results are in line with previous investigations in younger children showing no positive effects concerning CE physical activities. One might speculate that younger children may benefit from less cognitively engaging exercise forms, whereas older children may benefit from more complex exercises including changing rules etc. (Best, 2010). Hence, future studies should consider children's individual developmental level to adjust their CE in a physical activity intervention.

In contrast to previous results showing that age (Brocki & Bohlin, 2004; Pangelinan et al., 2011), gender (Pangelinan et al., 2011), physical fitness (Chang et al., 2012; Jäger et al., 2015; Hogan et al., 2013) and cognitive performance (Diamond & Lee, 2011) moderated the effects on children's EFs, the results of the current study indicate that the effect of the CE factor was independent of children's individual characteristics. Hence, immediate depletion effects of cognitively challenging physical activity breaks (lasting 20 min) can be expected in a broad range of typically developing children of 7–9 years of age.

The result of the CE factor may be explained by the strength model of self-control (Baumeister et al., 1998). Self-control is related to a mental capacity, e.g. cognitive resource that is depleted when people engage in behaviours that require self-regulation. Self-regulation and EFs share effort as a resource to successfully perform stressful or attentional demanding tasks (Audiffren, & André, 2015). The longer the duration of a cognitively challenging exercise, the higher the amount of self-control required to perform the exercise. In the current study, a high level of self-control resources was required to accomplish the high CE conditions. Moreover, the strength model of self-control predicts that a long lasting, vigorous, and uncomfortable exercise requires a high level of self-control resources. Therefore, self-regulation will be impaired in a subsequent task. In the current study, the high CE conditions consisted of 1) a long exercise duration of 20 min, 2) a moderate intensity, and 3) a high level of task-inherent shifting performances, such as shifting flexibly between visual and acoustic stimulus-response associations. As self-regulation behaviour shares the same resources as EFs, the subsequent shifting performance in the Flanker post-test was impaired. In other words, the children were ineffectively carrying out the subsequent Flanker task, especially in their ability to shift between the rules of different coloured fish.

In conclusion, the duration of an intervention, depending on the type (high or low amounts of CE) needs to be adapted in terms of the participant's age. Moreover, an individualized CE level of each physical activity is needed to reach children's optimal challenge point (representing the degree of functional task difficulty for each child; Guadagnoli & Lee, 2004). Thus, when children exercise in their specific skill level, a beneficial effect on cognitive function might be more probable (Pesce et al., 2013).

4.2. The absence of the main effect of physical exertion

Considering existing literature (Chang et al., 2012; Hillman, Kamijo, & Scudder, 2011) a positive effect of PE was expected. The results, however, showed no main effect for the PE factor. The current findings contradict studies showing acute effects of aerobic physical activities in children (Hillman, Pontifex, & Raine, 2009). The absence of a positive effect in the high PE conditions might be explained by its too low intensity. According to the meta-analysis of Chang et al. (2012), heart rates ranging between 70% and 85% of maximal heart rate, indicating moderate to vigorous intensity, seem to benefit the effect of cognitive performance the most. The PE condition in the current study elicited only 67% of the maximal heart rate, which might not be enough to reach optimal arousal. Results from the perceived physical exertion rate support this assumption.

Although participants of the high PE conditions reported a significantly higher level of perceived physical exertion compared to participants of the low PE condition, the former condition was rated as only "fairly light" in the 6–20 RPE scale. Best (2012), for example, who elicited a mean heart rate of 156 bpm in the high PE condition, reported increased performance in EFs in a laboratory setting. Also contrary to the current results of the high PE condition, Chen et al. (2014) showed better performances of the three core EFs after a 30-min jogging intervention at a moderate intensity (60–70% of the predicted max. heart rate). Since the preadolescents jogged in groups, the combination of social interaction and physical activity and not physical activity itself, might be responsible for the findings (Best, 2012). As speculated by Best (2010), the "social interactions during physical activities may explain the added benefits" of group activities on cognition.

4.3. Selective effects on shifting

The fact that only shifting, and not updating and inhibition, was affected by the CE factor needs to be discussed focusing on the selectivity of acute physical activity effects. Concerning the assessment of EFs in children, few studies (Benzing et al., 2016; Jäger et al., 2014, 2015) included all three core EFs as dependent variables targeting cognitively challenging interventions. The absence of an effect in updating is in line with the findings of Jäger et al. (2014, 2015) and Benzing et al. (2016), where the latter tested male adolescents in cognitively engaging physical activities. The current results contradict most previous studies investigating the effect of physical activity on inhibition with consistent evidence (e.g. Vazou & Smiley-Oyen, 2014). For example, Jäger et al. (2014) tested 6- to 8- year old children in a cognitively challenging physical activity intervention, and showed positive effects on inhibition. These results might be explained from a development point of view: Updating and inhibition are fully developed earlier (Davidson, Amso, Anderson, & Diamond, 2006) and are therefore not as easy to affect as other, not yet fully developed EFs, such as shifting (Diamond, 2013). A second explanation for the disparate findings could be the different development trajectories of the core EFs related to participants age ranges in the aforementioned studies. Results from a study providing a fine-grained analysis of age differences in complex EFs showed a dramatic increase in EFs between the ages of 5 and 8, followed by stagnancy through early adulthood (Best, Miller, & Naglieri, 2011). Shifting (compared to updating and inhibition) is a core EF, which is prone to changes through physical activity. As speculated by Schmidt et al. (2015), aspects of EFs which are not fully developed should be easier to change through physical activity interventions. As the current study shows, these changes can occur in varying directions. Shifting seems to be very sensitive with regard to cognitive engaging physical activities within the preadolescent period. Picking up on the theory of "supercompensation" from the applied training science, which implies a decrease in muscle performance immediately after an acute physical exercise, but increases after chronic physical activities, one can speculate that cognitively challenging physical activities have a similar effect on shifting. An overload of cognitive capacities performing physical activity may lead to an immediate decrease in shifting performance, however, after recovery, an increased performance after a chronic intervention seems reasonable. Two previous studies (Jäger et al., 2015; Schmidt et al., 2015) investigating acute as well as chronic effects of cognitive engaging physical activity on children's EFs may underline these suggestions. Whereas no beneficial effects of acute physical activity without CE were found, the chronic intervention showed an improved shifting performance after 6 weeks of a physical team game program with a high CE. These speculations could be tested in future studies by applying the current design for a chronic intervention.

4.4. Limitations and future directions

A major limitation of the current study is the fact that the individual levels of CE and PE were not adjusted during the physical activity breaks. A cognitive overload might be prevented by examining in advance relevant individual characteristics in sport-specific cognitive expertise, gross motor coordination and physical fitness (Pesce, 2009). Consequently, a personally fitted intervention for each subject would be possible. However, due to room and time limitations, implementing an individualized cognitive and physical level is a challenge for future studies, especially for classroom-based interventions.

Research still lacks a reliable and sensitive instrument to measure CE; hence no validated instrument was used for the manipulation check. One can only speculate whether the scale of perceived CE used really reflects CE. The usability of the adapted rating scale with the pictorial aid of the Self-Assessment-Manikin (Bradley & Lang, 1994) should be validated first. Previous studies, which tried to measure CE inherent in physical activity, used heart rate variability as an objective measurement (Benzing et al., 2016), or an adapted but not yet validated version of the Borg scale (Schmidt et al., 2016).

Future studies in field research should focus a) on the dose-response relationship of cognitively engaging physical activity in different childhood age classes and more importantly b) on the "quality-response relationship" (Pesce, 2012) systematically comparing the amount of CE inherent in physical activities. Therefore, the lack of instruments capable of measuring CE in children needs to be remedied first. Regardless to what extent cognitively challenging physical activity impacts cognitive performance, incorporating physical activity into existing classroom lessons is more child-orientated compared to a traditional classroom curriculum.

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