Embodied learning in the classroom: Effects on primary school children's attention and foreign language vocabulary learning

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Abstract
Objectives: The aim of the present study was to investigate the effects of specifically designed physical activities on primary school children's foreign language vocabulary learning and attentional performance.
Design: A total of 104 children aged between 8 and 10 years were assigned to either (a) an embodied learning condition consisting of task-relevant physical activities, (b) a physical activity condition involving task-irrelevant physical activities, or (c) a control condition consisting of a sedentary teaching style.
Within a 2-week teaching program, consisting of four learning sessions, children had to learn 20 foreign language words. Method: Children were tested on their memory performance (cued recall test) after completion of the program and on their focused attention (d2-R test of attention) immediately after one learning session. Results: Linear mixed model analyses revealed both the embodied learning (d = 1.12) and the physical activity condition (d = 0.51) as being more effective in teaching children new words than the control condition. Children's focused attention, however, did not differ between the three conditions. Conclusions: The results are discussed in the light of embodied cognition and cognitive load theory. Implications for the inclusion of specific physical activities during the school day are proposed.

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Embodied Learning in the Classroom: Effects on Primary School Children’s Attention and Foreign Language Vocabulary Learning
PHYSICAL ACTIVITY, ATTENTION AND LEARNING

Introduction

The central importance of movement for healthy child development is widely recognized in politics, science, and education. But despite growing evidence showing the benefits of regular physical activity for children’s physical (Poirtras et al., 2016) and mental health (Lubans et al., 2016), it appears that most school-aged children are not sufficiently active (Tremblay et al., 2014). The secular trend indicating a decline in children’s physical activity levels (Hallal et al., 2012) is not only alarming in terms of their physical health, but also in terms of their cognitive development. This concern comes from knowing that both motor and cognitive abilities are strongly interrelated and together predict academic achievement in young people (Donnelly et al., 2016; Oberer et al., 2018; Schmidt et al., 2017).

Therefore, political stakeholders, scientists as well as practitioners are calling for programs introducing more physical activity into schools to promote both the amount of daily physical activity and the cognitive performance of all school-aged children (Cox, Schofield, Kolt, 2010; Naylor & McKay, 2009).

Besides enhancing physical activity levels (e.g. Kibbe et al., 2011; Riley, Lubans, Holmes, & Morgan, 2016), classroom-based physical activity interventions seem to be effective at influencing academic-related outcomes (Erwin, 2012; Watson, 2017). Classroom-based physical activity can be distinguished into (1) physical activity breaks; consisting of short bouts of physical activity between the delivery of academic lessons and (2) integrated physical activity; incorporating physical activity during academic lessons (Webster, Russ, Vazou, Goh, & Erwin, 2015). Interestingly, these two types of classroom-based physical activity have been studied by different disciplines, through applying different methodologies referring to diverse theories to measure various outcome variables. Whereas exercise and cognition research has predominantly referred to the physiological changes induced by single bouts of gross motor exercise as an explanation for the effects of physical activity on cognitive functioning (Etnier, Salazar, Landers, Petruzzello, & Nowell, 1997; Khan & Hillman, 2014;
Lubans et al., 2016) and academic achievement (Donnelly et al., 2016), embodied cognition research has mainly focused on psychological explanations discussing them in the context of more subtle movements, such as gestures and more recently whole-body movements (e.g., Lindgren, Tscholl, Wang, & Johnson, 2016), influencing cognitive processes and learning (e.g., Goldin-Meadow & Beilock, 2010).

On the one hand, the effects of acute physical activity breaks have generally been researched by exercise scientists by targeting the main outcome variables of on- and off-task behaviour (Bartholomew et al., 2018; Howie, Beets, & Pate, 2014; Ma, Le Mare, Brendon, & Gurd, 2014; Riley et al., 2016), executive functions (Benzing, Heinks, Eggenberger, & Schmidt, 2016; Egger, Conzelmann & Schmidt, 2018; Howie, Schatz, & Pate, 2015; Jäger, Schmidt, Conzelmann, & Roebers, 2014; Jäger, Schmidt, Conzelmann, & Roebers, 2015; Kubesch et al., 2009) and attention (Best, 2012; Budde et al., 2008; Gallotta et al., 2012, 2015; Hill et al., 2010; Palmer, Miller, & Robinson, 2013; Schmidt, Benzing, & Kamer, 2016; van den Berg et al., 2016).

Studies investigating focused attention, an important prerequisite for learning (Steinmayr, Ziegler, & Träuble, 2010) defined as the voluntary act of trying to ignore certain stimuli while attending to others (Posner & DiGirolamo, 1998), have consistently reported positive effects when applying acute physical activity breaks ranging from 10 to 50 minutes in children and adolescents (Budde et al., 2008; Gallotta et al., 2012, 2015; Hill et al., 2010; Palmer et al., 2013; Schmidt et al., 2016; van den Berg et al., 2016). With respect to the content of these interventions, few attempts have been made to integrate cognitive learning tasks directly into the applied physical activity to facilitate the learning process of predefined academic concepts. Besides some notable exceptions (Pesce, Crova, Cereatti, Casella & Bellucci, 2009), studies have focused on acutely altered cognitive performance without considering the learning process itself (Álvarez-Bueno et al., 2017). However, considering that teachers report time constraints as being the most relevant barrier to implementing daily...
physical activity (Naylor et al., 2015), integrating physical activity into the learning of academic concepts may increase the added value of acute classroom-based physical activity.

When explaining the potential mechanisms underpinning the relationship between acute physical activity and cognition, the physiological responses provoked by acute (i.e., single bouts) physical activity include greater cerebral blood flow (Timinkul et al., 2008), increased release of various neurotrophins, e.g., brain-derived neurotrophic factor or nerve growth factor (Ferris Williams, & Shen, 2007; Winter et al., 2007), elevated glucocorticoid levels, e.g., cortisol (Blair, Granger, & Razza, 2005), and the release of catecholamines, e.g., epinephrine, norepinephrine, or dopamine (Winter et al., 2007). These neurophysiological changes are thought to lead to altered psychological states, such as increased arousal, making a larger pool of attentional resources available and therefore facilitating performance in cognitively effortful tasks (Audiffren, Tomporowski, & Zagrodnik, 2009).

Recently, researchers started recognizing the importance of the qualitative characteristics of physical activity interventions (Pesce, 2012; Pesce & Ben-Soussan, 2016), suggesting that various physical activities may not only differ in their intensity, duration, and frequency, but also, for example, in their coordinative and cognitive complexity (Vazou, Pesce, Lakes, & Smiley-Oyen, 2016). The basic assumption of the cognitive stimulation hypothesis, is that non-automated physical activities and coordinative demands activate the same brain regions that are used to control higher-order cognitive processes (Best, 2010; Pesce, 2012; Tomporowski et al., 2015). For the relation between acute physical activity and cognition, it is assumed that these cognitive demands during physical activity lead to better cognitive performance by pre-activating the same cognitive processes used in a subsequent cognitive task (Budde et al., 2008).

On the other hand, chronic physical activity studies generally focus on intervention effects on children’s on-task behavior (Bartholomew et al., 2011; Grieco et al., 2009; Mahar et al., 2006; Riley et al., 2016) or academic achievement (Beck et al., 2016; Donnelly et al., 2009;
Donnelly et al., 2017; Mullender-Wijnsma et al., 2016), instead of its effect on improving the learning of a certain academic concept through the physical activity itself. Physical activities, such as spelling some words by jumping in place for every letter during language learning (Mullender-Wijnsma et al., 2016), can be considered as non-task-relevant movements. Educational psychologists, however, are more concerned in finding specific movements which can be translated into academic concept. Based on the theoretical framework of embodied cognition, action and perception are inextricably bound, while sensorimotor experiences of the external environment are grounded in cognitive processes (Barsalou, 2008; Glenberg, Witt, & Metcalfe, 2013). In this sense, embodiment can be defined as the bodily states (i.e., arm movements and postures) arising from the interactions of the body with the semiotic world that are included in the cognitive processing. It is argued that embodying knowledge through motor actions contributes to the construction of higher-quality mental representations, facilitating recall, and enhancing memory and learning (Madan & Singhal, 2012). Complementary to the embodied cognition theory, the evolutionary upgrade of the cognitive load theory advocates the use of movements in learning complex tasks (Paas & Sweller, 2012). Considering the limitations in duration and capacity of the human cognitive architecture, a fundamental distinction can be drawn between biological primary and biological secondary knowledge. Biological primary knowledge includes automatized, implicit knowledge that the human brain has specifically evolved to process with limited working memory resources. This information can be used with little effort, and sometimes even unconsciously (e.g., movements, basic communication skills in one or more languages, entrenched language). In contrast, biological secondary knowledge includes non-automatized information based on culturally important knowledge that we have not specifically evolved to acquire. This information requires explicit instruction, such as formal schooling and deliberate practice (e.g., higher language cognition, advanced foreign language, mathematics), as well as substantial amounts of mental effort and cognitive resources to be devoted during learning.
Paas and Sweller (2012) have suggested that primary knowledge can be used to assist in the acquisition of biologically secondary knowledge. Consistent with this suggestion, several studies have shown that the use of biologically primary knowledge, such as gestures, can reduce working memory load and facilitate learning of biologically secondary knowledge, such as mathematics (e.g., Cook, Yip, & Goldin-Meadow, 2012; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Goldin-Meadow & Wagner, 2005).

More specifically, in the cognitive load theory, the total cognitive load on the learner’s cognitive resources is defined as the sum of the intrinsic and extraneous cognitive load (Sweller, 2010), both being linked with the physical learning environments of the learning task (Choi, Van Merriënboer, & Paas, 2014). Intrinsic cognitive load reflects the inherent complexity of the task, whereas extraneous cognitive load is related to the disruptive information from the physical characteristics of the learning tasks. In general, it is assumed that during learning of complex tasks, the available working memory resources are distributed between activities related to task performance (i.e., intrinsic load), and activities non-relevant to task performance (i.e., extraneous load).

Emerging empirical evidence supports the positive effects of gestures on learning mathematics (Cook et al., 2012; Goldin-Meadow, 2010), and whole-body movements in the form of physical activity on learning both mathematics (Shoval, 2011; Riley et al., 2016), and foreign language (Mavilidi, Okely, Chandler, Cliff, & Paas, 2015; Toumpaniari, Loyens, Mavilidi, & Paas, 2015). Focusing on the area of foreign language learning, two intervention studies in preschool children found that learning a second language was enhanced when children performed physical activity relevant to the meaning of the words to be learnt (i.e., integrated condition), when compared to a condition in which children were allowed only to gesture, and a condition representing the traditional sedentary instruction (Mavilidi et al., 2015; Toumpaniari et al., 2015). After four weeks, the authors of both studies attributed that the
enhanced learning performance observed in the children of the integrated condition was due to the task-relevancy of the included physical activities.

To the best of our knowledge, an existing gap remains for primary school children in the domain of language learning. Moreover, all these studies have examined the learning performance after chronic interventions without considering its acute impact on children’s attentional performance. In terms of setting appropriate timetables and choosing the right time to administer physical activity during the school day, it might be of considerable importance to understand the effects to children’s attention directly after a single session of embodied learning. Thus, the aim of the present study was to investigate the effects of specifically designed physical activities on primary school children’s foreign language vocabulary learning and attentional performance. Three experimental conditions were set up to engage children in learning exotic animal names in French, either combined with meaningful physical activity (embodied learning), nonrelated physical activity (physical activity), or without physical activity (control) included. The hypotheses were: (1) Children of both physically active conditions will outperform those of the control condition in their learning outcomes. (2) Based on the literature on embodied cognition, it is further hypothesized that children of the embodied learning condition will show the greatest learning outcomes. (3) Based on the literature deriving from exercise and cognition research, children of both physically active conditions should show better focused attentional performance immediately after a learning session than those of the control condition.

Material and methods

Subjects

Participants of the study were 104 children ($M_{age} = 9.04, SD = 0.70; 50$ girls) recruited from six elementary school classes in the region. These 3rd grade classes were randomly assigned to the experimental conditions, which resulted in two classes in the embodied learning condition consisting of task-related physical activities, two in the physical
activity condition involving task-unrelated physical activities, and two in the control condition consisting of a sedentary teaching style.

Based on the reported learning effects (after two weeks) of an embodied learning intervention on children’s cued recall performance in foreign language vocabulary learning (Mavilidi et al., 2015), an a priori power analysis (with 1 - beta error probability = .80; alpha error probability = .05; effect size $f = .314$; number of groups = 3) using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) was performed. An optimal sample size of $N = 102$ was calculated.

There was some loss of data due to sick leave or incompletely filled questionnaires. The percentage of pupils with incomplete values ranged between 3.1% for the accelerometers and 5.8% for the d2-R test of attention. Since Little’s Missing Completely at Random test (Little & Rubin, 2002) was not significant ($\chi^2 (231) = 186.60, p = .986$), the missing values were imputed using the expectation-maximization (EM) algorithm. There were no significant differences between the three experimental conditions with respect to age ($F(2, 101) = 1.09, p = .340, \eta^2_p = .021$), height ($F(2, 101) = 1.77, p = .175, \eta^2_p = .034$), weight ($F(2, 101) = 1.06, p = .349, \eta^2_p = .021$), BMI ($F(2, 101) = 0.84, p = .435, \eta^2_p = .016$), gender distribution ($\chi^2(2) = 1.32, p = .517, \text{Cramer’s } V = .113$), and socioeconomic status ($F(2, 101) = 0.48, p = .622, \eta^2_p = .009$).

The parents of the participating children signed an informed consent form approved by the Institutional Review Board prior to participating in the study. All children were 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.

**General Procedure**

The experimental procedure consisted of three phases: a pre-test, the instruction, and the post-test. Firstly, a pre-test was conducted to assess children’s prior knowledge by asking
them to name 38 exotic animal names from French to German. During the instruction phase, the learning sessions included 20 animal names in French (selected from the 38 list of the pre-test). The duration of the learning phase was 2 weeks, consisting of a 10-min session 2 days per week. The learning sessions were conducted by a trained research student, accompanied by a video played on a big screen ensuring that all learning sessions were identical in terms of the sequencing of the words, numbers of repetitions and duration. All the words were presented both auditory and visually (picture of the animal as well as the word itself) to the children. After being presented, the children had to repeat each word three times alternating between French and their mother tongue. This process was identical for all experimental conditions.

In addition, during the instruction phase, the participating classes were randomly assigned to one of the three experimental conditions: In the embodied learning condition, children had to enact the movements indicated by the animal name to be learned. For example, for the “short-tailed kangaroo”, the children hopped like a kangaroo and positioned their angled arms in front of their torso. In the physical activity condition, children had to perform movements of the same intensity, but without being related to the animal name e.g. simply running on the spot. In the control condition, all animal names were repeated equally as often as in the former two conditions, but while being seated at the desk.¹

Finally, the post-test phase included a wide range of additional data gathered at different time points to avoid overloading children with extensive testing procedures: 1) Before the beginning of first session, the d2-R test of attention (pre) was carried out. After the end of the first session, a questionnaire including background variables – age, gender, socioeconomic status (Boudreau & Poulin, 2009) – was filled out, and children’s height and weight were measured. 2) After the end of the second session, ratings of enjoyment, and cognitive exertion were obtained. 3) During the third session, children were wearing accelerometers. Immediately after this third session, the d2-R test of attention (post) was conducted. 4) After the fourth

¹ A list of the animal names and the respective videos can be obtained from the corresponding author.
session, the cued recall test was accomplished. All learning and testing sessions were conducted between 10.00 a.m. and 12.00 p.m.

**Manipulation Check and Control Variables**

*Physical activity* during the third learning session was objectively measured by using Light Move 3 accelerometers (movisens GmbH, Karlsruhe, Germany). The Light Move 3 is a three-axial acceleration sensor with a measurement range of +/- 8 g and a sampling rate of 64 Hz. Reliability and validity of the device has been proven by Anastasopoulou et al. (2014), using indirect calorimetry as a reference measure for activity energy expenditure. As recommended by Ekblom Nyberg, Ekblom Bak, Ekelund and Marcus (2012), the accelerometers were attached to the child’s non-dominant wrist, and based on body acceleration data, steps counts per minute were used as main outcome variable.

*Enjoyment* of the activity was measured by the German short version of the Physical Activity Enjoyment Scale (PACES; Motl et al., 2001). The PACES has been translated into German and validated by Jekauc, Voelkle, Wagner, Mewes and Woll (2013), proving to be a reliable and valid test for German-speaking children and adolescents. The short version (Dishman et al., 2005) only consists of the 7 negative items from the original scale, which are rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Thus, low scores indicate high enjoyment of the activity. In the current study, internal consistency was acceptable with a Cronbach’s alpha coefficient of .85.

*Cognitive exertion* was measured with an adapted version of the Self-Assessment Manikin (SAM; Bradley & Lang, 1994). The SAM is a widely used non-verbal pictorial assessment technique to measure an individual’s affective reactions to a variety of stimuli. Acceptable reliability and validity has been demonstrated in a sample of 7 to 11 year olds being able to make dimensional ratings of pleasure and arousal in similar ways to adults (McManis et al., 2001). As in the original SAM, the rating scale ranged from 1 (low) to 9 (high) on which the children had to rate their perceived cognitive exertion answering the question: “How
exhausting was the previous activity for your brain?”. Despite not being a validated instrument, its usability to rate cognitive effort of different activities has been shown in children and adolescent samples (Benzing et al., 2016; Egger et al., 2018).

**Experimental Measures**

To test children’s memory performance, an individual paper-and-pencil cued recall test was used. In this test, all 20 exotic animal names were displayed in German and the children had to write down the French word. There were no time constraints and depending on the ability of the child, the test took between 5 and 15 minutes. For each correctly recalled word, children received 1 point, with a minimum score of 0 and a maximum of 20. The recalled words were also considered correct when minor spelling errors or singular-plural substitutions had occurred.

To assess children’s attention, the d2-R test of attention (Brickenkamp et al., 2010), which is the revised version of the d2 test of attention (Brickenkamp & Zillmer, 1998), was used. The d2-R is a paper-and-pencil letter-cancellation test, consisting of 14 lines of 57 randomly mixed “p”s and “d”s, with one to four single quotation marks either above and/or below each letter. With 20 seconds allowed for each line, respondents are asked to strike out only the letter “d” with two dashes and to ignore all other distractors. After 20 seconds, the experimenter gives an acoustic signal, which tells the participants to move to the next line. The entire test duration is 4 minutes and 40 seconds. With no time constraints in the d2-R, virtually all subjects would solve all items correctly. However, the instruction to work as quickly and as accurately as possible leads to two types of errors: (1) omission errors, i.e. letters are omitted which should have been crossed out, and (2) commission errors, i.e. letters have been struck through that should have been left. The main outcome variable representing children’s focused attention is the number of correct responses minus commission errors. The resulting raw scores were transformed to scaled scores (Brickenkamp et al., 2010). High scores indicate high attention. Split-half reliability for the age-group of 9-10-year-olds ($r = .77$-.88) and test-retest
reliability with a time interval of 4 months ($r = .73-.88$) has been shown to be acceptable (Brickenkamp et al., 2010).

Statistical Analyses

All statistical tests have been conducted using Statistical Package for Social Sciences (SPSS 24.0). In the preliminary analyses, i.e. to analyze the manipulation check and control variables, analyses of variance (ANOVAs) were used. When the overall ANOVA proved significant, Bonferroni-corrected post-hoc comparisons were used to determine the specific differences between the three groups. For the main analyses, linear mixed models were used for memory performance and attention, as they are robust to the biases of missing data and provide appropriate balance of Type 1 and Type 2 errors (Krull & Mckinnon, 2001; Mallinckrodt, Watkin, Molenberghs, & Carroll, 2004). Memory performance in the cued recall test and children’s attention were used as dependent variables to test the impact of the three conditions on children’s memory performance and attention respectively. The level of significance was set at $p < .05$ for all analyses. Partial eta square ($\eta^2$) was reported as an estimate of effect size.

Results

Preliminary Analyses

To test whether the children in the two physically active conditions were more physically active than those in the sedentary condition, an ANOVA was conducted for their step counts per minute. Results showed that that there was a significant effect of condition on counts per minute ($F(2, 101) = 156.95, p < .0005, \eta^2_p = .757$), with post hoc comparisons revealing both the embodied learning ($p < .0005$) and the physical activity condition ($p < .0005$) being more physically exerting than the sedentary condition (Table 1). There was no difference between the two physically active conditions ($p = .145$).
The enjoyment varied significantly across conditions ($F(2, 101) = 5.69, p = .005, \eta_p^2 = .101$), with both the embodied learning ($p = .017$) and the physical activity ($p = .002$) condition being more pleasant than the sedentary condition. There was no difference between the two physically active conditions ($p = .437$). Interestingly, the perceived cognitive exertion also differed between the three conditions ($F(2, 101) = 3.77, p = .026, \eta_p^2 = .070$), with the control condition being experienced as being more cognitively exerting than the physical activity condition ($p = .023$), but not than the embodied learning condition ($p = .287$). The two physically active conditions did not differ in their amount of cognitive exertion induced ($p = .930$).

Main Analyses

To test the main hypotheses of the study, the three conditions were compared regarding their memory performance in the cued recall test. The ANOVA showed that there was not a significant difference between the conditions in children’s memory performance ($F(2, 3.03) = 1.25, p = .403$).

With respect to children’s focused attention immediately after the learning sessions, the pattern of results contradicts one of our main study hypotheses. Linear mixed models showed that the main effect of time ($F(1, 101) = 286.36, p \leq .001$). The main effect of condition was not significant ($F(2, 101) = 0.81, p = .448$). Also, a significant interaction between time and condition was found ($F(2, 101) = 8.48, p \leq .001$). In the post-test, children in the embodied learning condition performed the worse in the attention test compared to children in the control condition ($p = .020, d = .56$). The physical activity and control condition did not differ ($p = .627$). The physical activity and embodied conditions were marginally different ($p = .054, d = .47$).
The aim of the present study was to investigate the effects of two specifically designed physical activity interventions on primary school children’s foreign language vocabulary learning and attentional performance. Whereas the embodied learning condition consisted of task-related physical activities, the physical activity condition comprised of activities of the same intensity, which were, however, not related to the French words to be learnt. In the preliminary analyses, manipulation checks revealed that children of both the embodied learning and the physical activity condition were, not surprisingly, more physically active than their counterparts in the control condition. These results are in line with previous research showing embodied learning interventions (Mavilidi et al., 2015; Mavilidi, Okely, Chandler, Domazet, & Paas, 2018; Mavilidi, Okely, Chandler, & Paas, 2016, 2017) and physically active lessons (e.g., Kibbe et al., 2011; Riley et al., 2016) can enhance school children’s daily physical activity. Children of both the embodied learning and the physical activity condition enjoyed the lessons more than children in the sedentary condition. This finding reflects what has been found previously in recent studies comparing embodied learning interventions (Mavilidi et al., 2016, 2017, 2018) or integrated physical activity lessons (Mullender-Wijnsma et al., 2016; Riley et al., 2016; Vazou & Smiley-Oyen, 2014) to traditional sedentary teaching classes, with the result of higher values recorded in children’s positive affective reactions. Positively influencing children’s enjoyment though classroom-based physical activity is relevant for cognition, since changes in positive affect have been found to mediate the relationship between cognitive engaging activities and children’s attentional performance (Schmidt et al., 2016), being interpreted as additional support of mood being a facilitator for cognitive processing (Forgas & Eich, 2012; Isen, 2008). Thus, in future research, the affective outcomes of specific physical activities should be studied in more detail, to explore their role in enhancing
children’s cognitive performance by means of acute or chronic bouts of classroom-based physical activity.

Attention

The results of the main analyses showed that the embodied learning condition, which elicited the most pronounced learning effect, resulted in the worst attentional performance immediately after the learning sessions. In consistency with the study of Gallotta et al., (2012), children’s performance on the number of correct responses of the d2 test was not improved when children were assigned in a condition that involved coordinative physical education lesson with mixed cognitive and physical exertion. Based on the literature on the effects of acute bouts of physical activity in the school setting on children’s attentional performance (Budde et al., 2008; Gallotta et al., 2012, 2015; Hill et al., 2010; Palmer et al., 2013; Schmidt et al., 2016; van den Berg et al., 2016), our study hypothesis was that children of both physical activity conditions would show better attentional performance immediately after a learning session than children in the control condition. These conflicting results, therefore, cannot be explained by the aforementioned mechanisms discussed in previous studies investigating the effects of acute physical activity on school children’s cognition. Although focusing on different physiological parameters, such as cerebral blood flow (Timinkul et al., 2008), brain-derived neurotrophic factor or nerve growth factor (Ferris et al., 2007; Winter et al., 2007), glucocorticoids (Blair et al., 2005) or catecholamines (Winter et al., 2007), all these physiological changes are, generally speaking, assumed to lead to altered psychological states such as increased arousal, making a larger pool of attentional resources available and therefore facilitating performance in cognitively effortful tasks (Audiffren et al., 2009). In the current study, however, the objectively measured physical activity level did not differ between the two physically active conditions – but the attentional performance did. Therefore, it might be valuable to look at the differences between the conditions not in terms of their physiological but their cognitive properties, and consequently searching for explanations from systematically
investigating the amount of cognitive load being induced by different cognitive and physical activities for example (Paas, Renkl, & Sweller, 2003).

Previous research has shown that task-relevant physical activities within the instruction can save some cognitive resources to be used during learning (Ping & Goldin-Meadow, 2010). This was shown for co-speech gestures, which are normally made without conscious attention. However, in the present study a considerable amount of engagement, concentration, and attention was required from children in order to achieve the desired learning outcomes (Blumenfeld, Kempler, & Krajcik, 2006). Children of the embodied cognition condition not only had to learn the French words, but they also had to connect the words to the congruent movements to enact the meaning of the word. Connecting information deriving from two different sources might have resulted in more cognitive load in the embodied learning condition than in the physical activity condition, in which the learning task was combined with task-unrelated physical activities. This explanation seems partly supported by children’s self-reported measures of cognitive exertion: children in the control condition reported that their level of cognitive exertion was significantly higher compared to children in the physical activity condition, but not compared to the embodied learning condition.

As another theoretical explanation, children’s level of cognitive exertion can be linked to mental effort (Chen, Castro Alonso, Paas, & Sweller, 2018; Paas, Tuovinen, van Merriënboer, & Darabi, 2005). Hence, the multimodal information arising from the external learning environment of movements requires greater attention and concentration by children, resulting in a substantial depletion of their attentional resources, even if they were not aware of additional mental effort they invested. A possible explanation for children not being aware of the amount of mental effort they exert, is attributed to the factor of interest. Results in this study revealed that children in the embodied learning and physical activity conditions were found to have enjoyed the learning sessions more compared to children in the sedentary control condition. Intrinsic motivation aligned with the physical aspect of the leaning task, comprises
an important part of cognitive load theory and reflects the inherent interest of the learning activity, which has been shown to enhance attention and learning (Paas et al., 2005; Ryan & Deci, 2000; Wulf & Lethwaite, 2016). For future research it would be important to study the effects of task-related physical activities on the relationship between attention and learning.

**Learning**

The current study replicated the results of the studies of Mavilidi and colleagues (2015), and Toumpaniari and colleagues (2015) by showing that embodied learning of a foreign language vocabulary through task-relevant physical activities is more effective and enjoyable than the traditional sedentary way of learning. Although on a descriptive level, the children from the *embodied learning* condition remembered more words than their counterparts of the *physical activity* condition, the difference between the two physically active conditions was not statistically significant. The positive effects of task-relevant physical activity on learning outcomes aligns, however, with the embodied cognition and the cognitive load theory. The use of body movements during the learning process assists in transforming abstract information into concrete and tangible concepts (Hostetter & Alibali, 2008; Macedonia, 2014). Especially during foreign language learning, when newly learned words were encoded with movements, the motor image created was linked with the underlying mental representation of these words (Macedonia, Müller, & Friederici, 2011). Task-relevant movements can potentially create a richer trace in the long-term memory, and consequently enhance the process of memory retrieval, resulting in better recall (Madan & Sighn, 2012).

The sensorimotor experiences in the *embodied learning* condition allowed incoming information to be processed simultaneously through different modal sub-systems (i.e., seeing, hearing and enacting the words). From the perspective of cognitive load theory, this way of information processing is associated with a relative expansion the available processing capacity, enrichment of the resulting cognitive schema, and consequently better learning performance (Paas & Sweller, 2012; Risko & Gilbert, 2016). In terms of measuring cognitive
load, the extraneous cognitive load (i.e., disruptive information) should be reduced to allow working memory capacity to be devoted to intrinsic (i.e. task-related information) cognitive load (Sweller, 2010). In the present study, the relevance of the movements, which included sensorimotor information, could have led to the construction of higher-quality mental representations. Thus, external environmental influence which would be disruptive or redundant in other cases was converted into useful information, enhancing the learning process and deliberating the inherent intrinsic complexity of the task (Van Merriënboer & Sweller, 2005). In that sense, a better allocation of the working memory resources was achieved, with children of the embodied learning condition displaying the highest learning gains. Future research should try to investigate the effects of embodied learning on the different types of cognitive load, for example by using rating scales that can differentiate between the different types of load (e.g., Leppink, Paas, Van der Vleuten, Van Gog, & Van Merrienboer, 2013; Leppink, Paas, Van Gog, Van der Vleuten, & Van Merrienboer, 2014).

Finally, this study offers a unique contribution in the field by examining both acute and chronic effects of physical activity on attention and learning respectively. Also, we tried to intermingle interdisciplinary research providing with new conceptual interpretations using the theoretical frameworks based on the embodied cognition and cognitive load theory. However, some limitations can be noted: Firstly, even if medium effect sizes were found both for learning and attention scores, the duration of the intervention was relatively short. Future research should be consisted of interventions with longer duration that assess children’s attention and learning directly after multiple physical activity bouts. Importantly, including follow-up assessments, occurring several weeks after the end of the intervention (Mavilidi et al., 2015, 2018) will allow us to infer on whether any observed effects are maintained in the long run. Considering the contrast between the results on children’s cued-recall and attention scores, it is important to note that possibly a variety of motivational factors (such as perceived self-efficacy, novelty of the lesson, children’s enjoyment) may have positively affected
children’s learning performance. These factors may have facilitated children’s attentional resources during the lesson and as a result, led to enhanced learning performance (Davies, 1983), but they were not sufficient to maintain children’s attention levels at the end of the lesson. However, the significance of the embodiment effect is overshadowed, in the case that the aforementioned motivational factors may have attributed to the current results of learning performance.

Moreover, along with children’s assessments on learning progress, incorporating additional measures of standardized academic achievement (Donnelly et al., 2011) would enforce the generalizability of the results. Lastly, in the current study, children wore accelerometer during one learning session. Previous studies have used accelerometers only during the instruction phase or learning sessions (Mavilidi et al., 2015, 2016, 2017, 2018). However, comparing children’s physical activity levels across school day by giving children to wear accelerometers for one week during school time before the intervention, and for one week when the intervention is running (Riley et al., 2016), would produce a more representative sample of children’s physical activity levels. Alternatively, heart rates monitors have previously been used in studies on acute effects of exercise on children’s executive functions to identify physical activity levels (Best, 2012; Budde et al., 2008).

Conclusions

Overall, the results of this study reveal some insightful practical implications for practitioners and stakeholders: Embodied learning in the form of task-relevant movements is recommended to get a prominent place within the traditional sedentary curriculum. Academic content is not compromised, instead it is enhanced and empowered, as children learn better and more profoundly using this approach. Concomitantly, children seem to enjoy this type of learning more than the traditional sedentary type of learning and their motivation to participate in learning is higher. However, the results also suggest that the embodied way of learning is
cognitively more demanding than the sedentary way of learning, and therefore should not
overlap with other cognitive activities, such as exams, complex and difficult assignments, to
prevent children from becoming overloaded.

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### Table 1

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

<table>
<thead>
<tr>
<th></th>
<th>Embodied learning (n = 34)</th>
<th>Physical activity (n = 37)</th>
<th>Control (n = 33)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>8.92 (0.67)</td>
<td>9.16 (0.64)</td>
<td>9.03 (0.77)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>141.23 (6.41)</td>
<td>139.24 (6.83)</td>
<td>137.70 (6.10)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>35.71 (6.79)</td>
<td>33.36 (6.86)</td>
<td>33.77 (7.80)</td>
</tr>
<tr>
<td>BMI (kg · m⁻²)</td>
<td>17.81 (2.59)</td>
<td>17.05 (2.25)</td>
<td>17.67 (3.03)</td>
</tr>
<tr>
<td>Gender distribution (male/female)</td>
<td>15/19</td>
<td>20/17</td>
<td>19/14</td>
</tr>
<tr>
<td>Socioeconomic status (0-9)</td>
<td>6.12 (1.82)</td>
<td>6.41 (1.54)</td>
<td>6.00 (2.03)</td>
</tr>
<tr>
<td><strong>Manipulation check and control variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical activity (steps/min)*</td>
<td>38.41 (10.92)⁹</td>
<td>33.93 (11.68)⁹</td>
<td>1.08 (2.10)¹⁰,a,b</td>
</tr>
<tr>
<td>Enjoyment (1-5)*</td>
<td>1.48 (0.73)⁹</td>
<td>1.36 (0.47)⁹</td>
<td>1.84 (0.64)¹⁰,a,b</td>
</tr>
<tr>
<td>Cognitive exertion (1-9)*</td>
<td>4.01 (2.27)</td>
<td>3.55 (1.73)⁹</td>
<td>4.79 (1.60)¹⁰</td>
</tr>
<tr>
<td><strong>Experimental measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued recall performance*</td>
<td>4.72 (2.45)⁹</td>
<td>3.83 (3.45)</td>
<td>2.28 (1.62)¹⁰</td>
</tr>
<tr>
<td>Attention performance (pre)</td>
<td>97.03 (11.27)</td>
<td>97.68 (7.80)</td>
<td>94.82 (12.66)</td>
</tr>
<tr>
<td>Attention performance (post)*</td>
<td>107.17 (12.39)¹⁰,²,e</td>
<td>112.49 (10.34)⁹</td>
<td>113.83 (11.76)⁹</td>
</tr>
</tbody>
</table>

*Note. BMI = body mass index. *p < .05. Significant differences of (Bonferroni corrected) post-hoc comparisons are indicated by respective letters (a = Embodied learning; b = Physical activity; c = Control). In enjoyment ratings, lower scores indicate higher enjoyment.