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Effects of Integrating Physical Activities Into a Science Lesson on Preschool Children's Learning and Enjoyment

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Summary: This study investigated the effects of physical activities that were integrated into a science lesson on learning among preschool children. A total of 90 children from seven childcare centres (M_{age} = 4.90, SD = 0.52; 45 girls) were randomly assigned across an integrated physical activity condition including task-relevant physical activities, a nonintegrated physical activity condition involving task-irrelevant physical activities, or a control condition involving the predominantly conventional sedentary style of teaching. Children learned the names of the planets and their order, based on the distance from the sun. For both the immediate and delayed (6 weeks after the programme) assessments, results showed that learning outcomes were highest in the integrated condition and higher in the nonintegrated condition than in the control condition. Children in the integrated condition scored higher on perceived enjoyment of learning than children in the control condition. Implications of integrated physical activity programmes for preschool children's health, cognition, and learning are further discussed. Copyright © 2017 John Wiley & Sons, Ltd.

INTRODUCTION

Young children are particularly enthusiastic about discovering the physical environment that surrounds them. Part of this interest stems from the tangible and specific ideas of concrete objects or animals—as opposed to abstract concepts—that are part of this environment. The first developmental theories of Piaget (1970) and Vygotsky (1962) emphasized the critical role of motor actions in human learning. When it comes to science learning, this is especially important as children have to abandon their beliefs or perceptions and progress through a conceptual change in order to develop more complex representational structures (Carey, 2000). To this vein, physical experience through observation and manipulation appears to be essential for promoting young children's novel conceptual understanding in science (Gelman & Brenneman, 2004; Zacharia, Loizou, & Papaevripidou, 2012). For example, spatial thinking, which is critical to success in science, technology, engineering, and mathematics disciplines, can be improved by the use of symbolic representations, analogies, and gestures (Uttal, Miller, & Newcombe, 2013). Intervention studies, using the theoretical framework of embodied cognition, have shown that physical experience, for example, in the form of object manipulation, can embody knowledge and enhance learning of science (see e.g. Boncoddo, Dixon, & Kelley, 2010; Kontra, Lyons, Fischer, & Beilock, 2015; Lindgren & Johnson-Glenberg, 2013). Similar effects have been found in the domains of language (e.g. Mavilidi, Okely, Chandler, Cliff, & Paas, 2015) and geography (Mavilidi, Okely, Chandler, & Paas, 2016), when the knowledge was embodied through movements in the form of physical activities. In this study, we aimed to follow up on these studies by investigating the effects of infusing physical activities in preschool children's science learning on learning outcomes.

Research on human movements can generally be categorized into studies including subtle movements such as gestures or studies including gross motor movements such as physical activity. Whereas the research on subtle movements mainly focuses on effects on cognition, research on physical activity mainly focuses on effects on health. The first part of this article presents the underlying theory and empirical evidence linking actions during learning (Madan & Singhal, 2012; Moreau, 2015; Pouw, Van Gog, & Paas, 2014). In addition, the health and cognitive benefits of physical activity and how these benefits can be extended into education will be described (Owen et al., 2016; Sibley & Etnier, 2003).

Perception and action are closely intertwined (Gallagher, 2005; Wilson, 2002). It is believed that cognition is grounded in different ways consisting of mental simulations, situated action, and bodily states. Movements play an essential role in learning and instruction (Ayres, Marcus, Chan, & Qian, 2009). The body acquires a dominant role in cognition with a combination of perceptual and sensorimotor experiences forming multimodal representations in memory (Barsalou, 2008; Barsalou, Simmons, Barbey, & Wilson, 2003). These representations supply alternative routes for memory retrieval, because they are enriched with motor information (Madan & Singhal, 2012; Plummer, 2009). The enactment effect was initially built upon the foundation that actions are better recalled when they are performed compared with when they are heard or read (Engelkamp & Zimmer, 1989). Through embodied learning, embodiment, which refers to the enactment of concepts by using the body, ranges from neuromuscular activation of low embodiment, in which only movements of fingers are involved, to high embodiment with full body movements engaged, relying on multimodal encoding methods to elicit higher retention and transfer of

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learning (Lindgren & Johnson-Glenberg, 2013). Education researchers have proposed enactive metaphors during learning through whole-body movements as a way to instigate learning in science (Gallagher & Lindgren, 2015). For instance, mixed reality environments use action-concept congruencies where children can learn about laws of physics (e.g. gravitational force) by simulating the movements of asteroids in empty space or the orbits of planets by moving across floor-projected virtual environment, walking in a straight line, or moving faster or slower depending on children's distance to the planets (Lindgren & Johnson-Glenberg, 2013; Lindgren, Tscholl, Wang, & Johnson, 2016). Comparing middle school students in an experimental condition, in which they were engaged in whole-body movements simulations, to a control condition by using a desktop version of the simulation (i.e. movements by clicking a computer mouse), Lindgren et al. (2016) found that the learning gains as well as children's engagement levels were more pronounced in the experimental condition. Likewise, Plummer (2009) noted significant learning gains in the development of astronomy concepts in first and second grade students, through kinesthetic learning techniques in the planetarium, whereby they performed celestial trajectories with their bodies or objects representing stars and planets.

The importance of physical experience in science learning through engagement in whole body movements is well accepted. However, it seems important to examine whether there is a relationship between the full-body movements in the form of physical activity and cognition. Physical activity can be defined as 'any bodily movement produced by the contraction of skeletal muscle that can increase energy expenditure above a certain level, whereas exercise is considered as a sub-category of physical activity that is planned, structured, and repetitive, focusing on the improvement or maintenance of one or more components of physical fitness, physical performance, or health' (Centre for Disease Control and Prevention, 2016). Research has gleaned insight into the association between physical activity and fitness with health benefits such as muscle and bone strengthening, better cardiometabolic health, prevention of chronic diseases (e.g. obesity, cholesterol, high blood pressure, type 2 diabetes, cardiovascular disease, and cancer), reduction of depression and stress, better states of mood, and improved self-esteem and body image (Baranowski et al., 1992; Janssen & LeBlanc, 2010; Penedo & Dahn, 2005; Sothern, Loftin, Suskind, Udall, & Blecker, 1999; Warburton, Nicol, & Bredin, 2006; World Health Organization, 2015). Physical activity has also been related to cognitive benefits such as improved cerebral activity and enhanced brain development (e.g. better neural connections and improved blood flow and oxygenation), cognitive functioning (e.g. cognitive control, attention, and memory), and academic performance in children (Chaddock-Heyman et al., 2016; Drollette et al., 2014; Erickson, Hillman, & Kramer, 2015; Fedewa & Ahn, 2011; Hillman, Castelli, & Buck, 2005; Kamijo, Takeda, Takai, & Haramura, 2015; Khan & Hillman, 2014; Rasberry et al., 2011; Sibley & Etnier, 2003; Tomporowski, Davis, Miller, & Naglieri, 2008). It is suggested that, in order to cultivate the potential for these salient benefits to occur, it should commence in early childhood education and care settings, widely recognized as a place for holistic learning characterized by physical, social, and emotional development and determined by scaffolding of behavioural patterns (Barnett, 2008; Lu & Montague, 2016).

Intervention programmes to increase physical activity levels and positively affect academic achievement have been successfully established in elementary school settings. These studies have incorporated classroom-based physical activities in the academic lessons of various learning areas such as maths, language, science, social sciences, and general health (Donnelly & Lambourne, 2011; Kibbe et al., 2011; Mahar, 2011; Mahar et al., 2006; Tarp et al., 2016). Based on these studies, Grieco, Jowers, Errisuriz, and Bartholomew (2016) focused on the dosage of physical activity intensity required to improve on-task behaviour. Results revealed that both a low dose of low-to-moderate physical activity as well as a higher dose of moderate-to-vigorous physical activity (MVPA) can increase children's on-task behaviour compared with traditional sedentary more lessons. The magnitude of the effects shown was similar to Mahar et al. (2006). Finally, a series of studies objectively measuring physical activity and learning outcomes in preschool children found improvements in academic performance and increase in physical activity levels during learning of foreign language vocabulary and geography combined with whole-body movements (Mavilidi et al., 2015, 2016).

The current study will assess the effects of whole-body movements on preschool children's learning in science by objectively gauging learning and physical activity outcomes. A solar system task was chosen for preschool children as a foundational introduction in the domain of science. More complex and developed concepts such as the celestial motion (how the sun, the moon, and the stars move) are considered as an acquired knowledge for children in early elementary school (*Benchmarks*; American Association for the Advancement of Science, 1994; Plummer, 2009).

In this study, three experimental conditions will engage children in a solar system task combined with meaningful physical activities, nonrelated physical activities, or without physical activities included. In the integrated condition, children will perform movements related to the learning content. In this condition, children will run starting from the position of the sun to the closest planet (i.e. Mercury). In the nonintegrated condition, movements will be unrelated to the task and children will run around the classroom for several minutes. Finally, the control condition will represent the conventional way of teaching, in which children will stay seated and observe the planets. It is expected that the conditions that include movements (integrated and nonintegrated condition) will outperform the control condition (Hypothesis 1). Moreover, based on the combined embodied and physiological effects, it is assumed that the integrated condition will show the highest learning outcomes (Hypothesis 2). Finally, children in each condition will evaluate how much they enjoyed the way they learned. It is hypothesized that the integrated condition will show the highest scores for perceived enjoyment of the learning method (Hypothesis 3).

METHOD

Participants

This study was approved by the Human Research Ethics Committee of the University of Wollongong (HE15/458). Seven early childhood centres from the Illawara area of NSW, Australia were included in this study (Figure 1). Each centre director and the child's parents provided their written consent forms for their children's participation in the study. A total of 90 typically developing children (no diagnosis of mental illness, disorders, or learning difficulties) participated in this study ($M_{\text{age}} = 4.90$, $SD = 0.52$; 45 girls; 2.3% Aboriginal; 1.1% for American, French, Indian, Indonesian, Irish, Vietnamese, Russian, Spanish, and Serbian; 2.3% British; and 3.4% Chinese). The existence of low income healthcare card or pension card from Centrelink was used as an index of socioeconomic status (Australian Government Department of Human Rights, 2016). The index indicated that the population of this study consisted of mainly medium-to-high socioeconomic status. There were no differences among the conditions in terms of demographic characteristics (Table 1). Three children were excluded from the analyses because of a general reluctance to participate and one child due to missing data. Randomization occurred at centre level and per condition (each centre was aligned to one/several different conditions), resulting in 30 enrolled in the integrated condition, 27 in the nonintegrated condition, and 29 in the control condition. Stickers were given as a reward for children's effort at the end of each learning and testing session.

Procedure and materials

The researcher visited the childcare centres and coordinated the learning and testing sessions. The learning sessions consisted of a solar system task (i.e. name of planets and their right order based on their distance from the sun). The learning sessions took place in small groups (max 10 children), once per week, for 4 weeks. The testing session occurred individually at three time points: A pretest was administered before the first learning session to assess children's prior knowledge, an immediate post-test directly after the end of the last learning session, and a delayed post-test 6 weeks after the last learning sessions. The two post-tests determined the knowledge children had acquired during the learning sessions.

During the learning sessions, a picture of the sun and the planets in space (on a straight line) was placed at a central point easily to be seen by all children. Also, 'toy' planets were placed in a line on the floor in the same order, corresponding to the planets in the pictures. The children had to remember the names of the planets and their correct order starting from the planet closest to the sun, Mercury, through to the planet furthest from the sun, Neptune. The instructor began with a small introduction of the concept of space and the planets.

The children were assigned to a condition at a centre level. However, some centres were enrolled in more than one condition. In these cases, each group ran on different days with different children and at the completion of the previous group to avoid contamination of the conditions. The instructor called aloud the name of the planets in all conditions. In the integrated condition, the children performed physical activities related to the learning task.

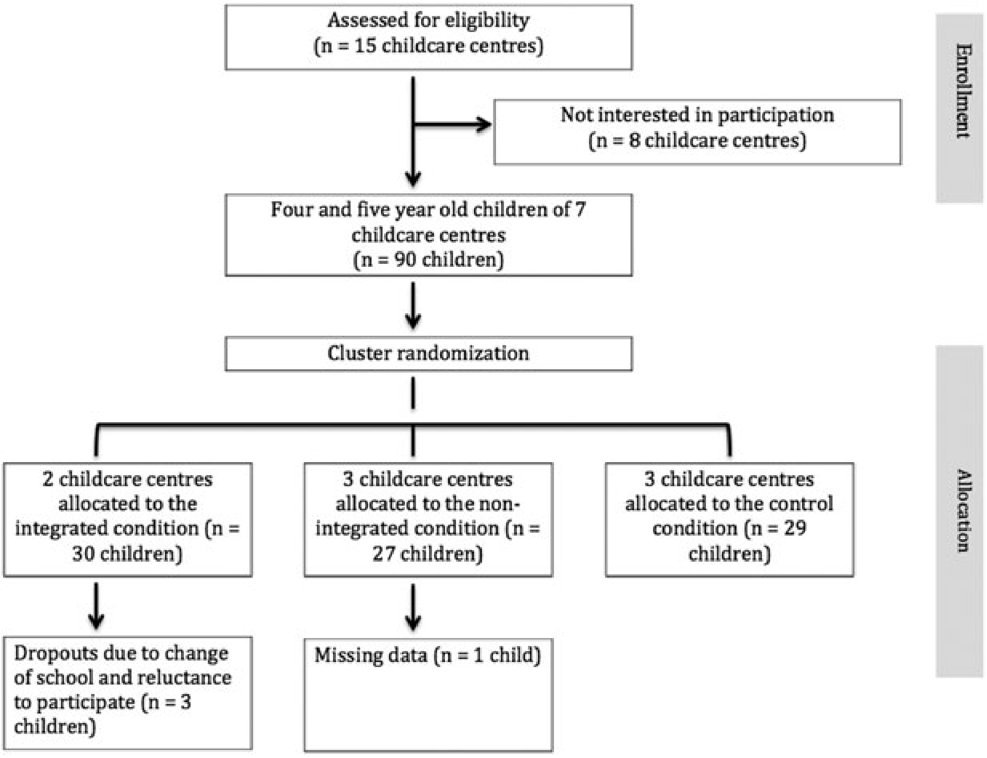

Figure 1. Chart flow of schools and children from enrolment and allocation

Table 1. Participants' demographics stratified by condition

	Total	Integrated condition	Nonintegrated condition	Control condition	*p*-value
Age, years (*SD*)	4.90 (0.52)	4.96 (0.51)	5.10 (0.43)	4.80 (0.44)	.118[a]
Gender, *N* boys (%)	49.4	54.8	40.7	51.7	.538[b]
Ethnicity, *N* Australian (%)	74.7	90.3	70.4	62.1	.269[b]
Healthcare card or pension card, *N* no (%)[c]	92	96.6	85.2	93.5	.284[b]

[a] ANOVA.
[b] χ^2 test.
[c] As an index of socioeconomic status.

Starting from the sun, they visited the first planet and then they returned back to the sun. Then, they visited the second planet and returned back to the sun. They did the same actions for all the planets. In the nonintegrated condition, the children performed physical activities unrelated to the learning task. Firstly, the children ran a lap around the room. Then, they sat and listened to all the names of the planets. They followed the same process three times. In the control condition, no physical activities were involved. The children remained seated while observing the planets (the first planet was the one closer to the sun until the one furthest from the sun). During each learning session, which lasted 10 minutes per day for all conditions, the names of the planets were repeated three times in all conditions.

During the testing sessions, the children were evaluated on their ability to recall the names of the planets and their appropriate order starting from Mercury. The cognitive tests included the following:

Free-recall test:
The children were asked to name any planet they could remember. Next, they were asked to place the toy planets in a straight line, starting with Mercury and finishing with Neptune.

Cued-recall test: The children were shown pictures of four planets and were asked to name them (i.e. Venus, Mars, Earth, and Uranus). Also, the children were given four toy planets and were asked to place them in the right order based on their distance from the sun, starting with the planet that is closest to the sun (i.e. Mercury, Jupiter, Saturn, and Neptune). Finally, the children were shown four toy planets and were asked to name them (i.e. Mercury, Earth, Uranus, and Neptune).

The children received one point for each correct answer. The maximum score that children could obtain was 28. This method was based on Best, Dockrell, and Braisby's (2006) method to evaluate older children's knowledge about the eclipse and entities related to space. A reliability coefficient (Cronbach's alpha) of .84 was found for the testing materials.

Physical activity was objectively assessed by using accelerometers (model GT1M, Pensacola, FL). The sampling interval (epoch) was set at 1 second to best capture variability in children's activity (Cliff, Reilly, & Okely, 2009). Parents (via written consent forms) were informed that their children would wear the accelerometer during the learning sessions. The accelerometers were affixed to an elastic belt and placed by trained staff around the child's waist so that the accelerometer was at the top of their right hip at the beginning of the lesson and were removed at the end of the lesson. The accelerometers were processed by using ACTILIFE v6.12.1 software and were recorded for the scheduled 10-minute period. The time spent per lesson in various intensities was calculated by using child-specific cutpoints (Pate, Almeida, McIver, Pfeiffer, & Dowda, 2006). These cutpoints have been shown to be the most accurate in young children (Janssen et al., 2013). Data were reported as minutes spent in moderate-to-vigorous intensity physical activity and the average activity counts per minute, representing the total activity intensity during the lesson.

At the end of the immediate post-test and delayed post-test, the children evaluated how much they liked the type of instruction ('Did you like this game') and if they would like to be taught this way in the future ('Would you like to play it again in the future?') on a 5-point Likert scale with response scores ranging from 1, 'I didn't like it all', to 5, 'I liked it a lot', and 1, 'Not at all' to 5, 'I would love to' respectively. These were supplemented with a visual scale of smiley faces ranging from 1 to 5, corresponding to the two questions. The interest ratings were computed as the average scores on these questions. This scale was adapted from the study of Mavilidi et al. (2016). A coefficient alpha of .85 was obtained for these questions in this study.

Statistical analyses

A randomized control trial was conducted to assess the effectiveness of the suggested instructional approaches on children's learning outcomes and children's interest after the intervention. Physical activity outcomes were included in the analyses to confirm our basic assumption that children would be more physically active in the physical activity conditions (integrated and nonintegrated) than in the sedentary control condition. To control for baseline differences in demographic characteristics among the conditions (age, gender, ethnicity, and socioeconomic status), analysis of variance (ANOVA) and χ^2 tests were used. Separate analyses were conducted for the learning outcomes, interest ratings for the instructional method, and physical activity outcomes. With regard to the learning outcomes, a cluster design was chosen initially because the intervention was structured in seven childcare centres, where childcare centre was treated as a random variable with children nested in preschools and in conditions (integrated vs nonintegrated vs control). The childcare centre, children's ethnicity, socioeconomic status, and gender were set as the cluster units for the randomization. Because the analyses produced similar results and none of the demographics characteristics seem to be a confounder, we chose to perform a mixed 3 (condition: integrated physical activity, nonintegrated physical activity, and control) × 2 (time of testing: immediate post test and delayed post test) experimental design with repeated measures on the latter factor, accounting for possible interaction effects. The independent variables were condition and time of testing, and the covariate was children's pretest scores. The same experimental design was used to look for differential effects of condition on the children's interest scores (excluding the covariate).

Finally, the differences in physical activity outcomes among the conditions were examined in two separate analyses for counts per minute and time spent in moderate-to-vigorous intensity physical activity.

The datasets were controlled for outliers, normality of the distribution, homogeneity of variance, and sphericity (when required; Field, 2009). The analyses were performed by using SPSS and STATA. The significance level was set at .05, and η^2 was used as an estimate of effect size, with $\eta^2 = 0.02$ corresponding to a small effect, $\eta^2 = 0.13$ corresponding to a moderate effect, and $\eta^2 = 0.26$ corresponding to a large effect (Cohen, 1988, 1992).

RESULTS

Learning outcomes

An ANOVA was run before the main analysis. This analysis yielded no significant differences among the conditions in the pretest scores, $F(2,84) = 0.08$, $p = .922$ (integrated condition, $M = 1.58$, $SE = 0.38$, 95% CI 0.82, 2.34; nonintegrated condition, $M = 1.37$, $SE = 0.41$, 95% CI 0.56–2.18; control condition, $M = 1.55$, $SE = 0.39$, 95% CI 0.77–2.33).

The results from the mixed ANCOVA revealed that the covariate, pretest scores had a significant effect on learning scores, $F(1,82) = 12.44$, $p \leq .001$, $\eta_p^2 = 0.13$. After controlling for the covariate, pretest scores, there were significant main effects of condition, $F(2,82) = 34.98$, $p \leq .001$, $\eta_p^2 = 0.46$, and time of testing, $F(1,82) = 16.15$, $p \leq .001$, $\eta_p^2 = 0.17$, on learning performance. Although the interaction between time of testing and the covariate, pretest scores was not significant, $F(1,82) < 1$, $p = .177$, the main effects were qualified by a significant interaction between condition and time of testing, $F(2,82) = 6.17$, $p = .003$, $\eta_p^2 = 0.13$. Post-hoc comparisons with Bonferroni correction, controlling for type I error, revealed that the integrated condition ($M = 14.05$, $SE = 0.73$, 95% CI 12.59–15.51) performed better than the nonintegrated ($M = 10.11$, $SE = 0.78$, 95% CI 8.56–11.65, $p \leq .001$) and control conditions ($M = 5.28$, $SE = 0.75$, 95% CI 3.79–6.77, $p \leq .001$). Also, the nonintegrated ($p \leq .001$) and control conditions ($p \leq .001$) significantly differed. Table 2 presents descriptive statistics for science scores for all conditions during the two time points of testing.

Table 2. Means and standard deviations for performance and instruction evaluation at the immediate and delayed tests as a function of the condition

Time of testing	Performance *M* (*SD*)	Evaluation *M* (*SD*)
Pretest scores (0–28)		
Integrated condition	1.58 (1.67)	
Nonintegrated condition	1.37 (1.82)	
Control condition	1.55 (2.72)	
Immediate post test (0–28)		
Integrated condition	15.53 (4.91)	4.35 (1.05)
Nonintegrated condition	11.07 (5.04)	3.98 (.91)
Control condition	5.52 (4.37)	3.67 (1.17)
Delayed post test (0–28)		
Integrated condition	12.63 (5.08)	4.37 (.82)
Nonintegrated condition	8.97 (4.14)	3.91 (1.00)
Control condition	5.14 (3.36)	3.31 (.88)

Furthermore, pairwise comparisons with Bonferroni correction showed that the children performed better in the immediate post test ($M = 10.71$, $SE = 0.48$, 95% CI 9.75–11.67, $p \leq .001$) than the delayed post test ($M = 8.91$, $SE = 0.44$, 95% CI 8.04–9.79, $p \leq .001$).

Interest ratings for instructional method

A mixed ANOVA was run to assess children's interest across the conditions. The interest ratings were measured at two moments, directly after the end (immediate post test) and 6 weeks after the intervention (delayed post test). Table 2 presents descriptive statistics for children's interest for the three conditions during the two time points of testing. The analysis revealed that the main effect of time of testing was not significant, $F(1,83) = 1.98$, $p = .164$. However, there was a significant main effect of condition, $F(2,83) = 7.43$, $p \leq .001$, $\eta_p^2 = 0.15$. The interaction between condition and time of testing was not significant, $F(2,83) = 1.34$, $p = .267$. With regard to the main effect of condition, post-hoc comparisons revealed that children in the integrated condition ($M = 4.36$, $SE = 0.16$, 95% CI 4.05–4.67) gave higher ratings for enjoyment of their way of learning than children in the control condition ($M = 3.49$, $SE = 0.16$, 95% CI 3.17–3.81, $ps \leq .001$) did for their specific way of learning. However, the ratings in the nonintegrated condition ($M = 3.94$, $SE = 0.17$, 95% CI 3.61–4.28) did not differ from ratings in the integrated ($p = .075$) and control ($p = .053$) conditions.

Physical activity outcomes

An ANOVA was performed to assess the intensity levels of physical activity across the conditions, with counts per minute as dependent variable and condition as independent variable. The results showed a significant effect of condition on counts per minute, $F(2,215) = 26.13$, $p \leq .001$, $\eta_p^2 = 0.19$. Post-hoc comparisons with Hochberg correction, controlling for different sample sizes, revealed that the children in the nonintegrated condition ($M = 1117.00$, $SE = 53.57$, 95% CI 1011.42–1222.59) were more physically active than the children in the integrated condition ($M = 878.23$, $SE = 53.57$, 95% CI 780.85–975.61, $p = .004$). The children in the integrated and nonintegrated conditions were more physically active than the children in the control condition ($M = 530.27$, $SE = 61.04$, 95% CI 409.96–650.57, both $ps \leq .001$).

Moreover, an ANOVA was performed on the total time spent in MVPA, with condition as the independent variable. The results showed that there was a significant effect of condition on time spent in MVPA, $F(2,215) = 40.92$, $p \leq .001$, $\eta_p^2 = 0.27$. Post-hoc comparisons with Games–Howell correction, controlling for unequal variances, showed that the children in the nonintegrated condition ($M = 2.25$, $SE = 0.09$, 95% CI 2.06–2.43) spent more time in MVPA than the children in the integrated condition ($M = 1.62$, $SE = 0.09$, 95% CI 1.46–1.79, $p \leq .001$). Moreover, the children in the integrated and nonintegrated conditions spent more time in MVPA than the children in the control condition ($M = 0.98$, $SE = 0.11$, 95% CI 0.77–1.19, both ps $\leq .001$).

DISCUSSION

The purpose of this study was to investigate the learning effects of integrating physical activities into a science lesson among preschool children. The results confirmed the hypotheses, indicating that the integrated physical activity condition, in which children embodied science knowledge through physical activities, had the highest learning outcomes, assessed by a combination of free-recall and cued-recall tests directly after and 6 weeks after the end of the intervention. In addition to that, the nonintegrated condition, which involved task-irrelevant movement, performed better than the sedentary control condition (Hypothesis 1). The outcomes of this study reflect the effects of task-relevant whole and part-body movements on learning outcomes found in past research (Boncoddo et al., 2010; Donnelly & Lambourne, 2011; Gallagher & Lindgren, 2015; Mavilidi et al., 2015, 2016). Intervention studies attest the importance of the use of body movements, specifically for science learning. For example, Kontra et al. (2015) evaluated the importance of physical experience in science learning in college students. Through a series of studies, the students learned about the vector nature of angular momentum. Firstly, during the training, they observed avatars on videos, and afterwards, they were paired to an action group in which they had to physically manipulate aspects of a wheel system (e.g. direction, spin, speed, size, and tilt) or an observation group in which they could observe the tilting and the path of a red laser dot on the wall. The test trials included wheels spun in the same and opposite directions to those in the training sessions. Also, the neural correlates of the learning path of the participants were recorded by using functional magnetic resonance imaging. Finally, it was examined whether the effects of action experience would remain after several days of engagement in the bicycle-wheel system. It was found that students who were able to physically manipulate the angular momentum outperformed students who only observed the same phenomena. Action experience activated their sensorimotor brain systems and fostered their understanding of the physics concepts. Moreover, Boncoddo et al. (2010) examined whether meaningful hand movements had an effect on preschool children's learning of simple gear-system problems. Firstly, the children familiarized themselves with the properties of the gears by physically manipulating toy gears and then they solved the gear-system problems on a computer. The results displayed that, when the children used a force-tracing strategy (i.e. by choosing which clockwise–counterclockwise motions they had to make to solve how gears alternate turning direction), they were able to solve the gear problems faster. The interaction between children's movements and the gear system enabled them to acquire novel representations of physics from their own actions.

Importantly, the essential role of physical experience and linking knowledge to real-world examples during science learning is emphasized for improving spatial abilities (Hegarty & Waller, 2005), the construction of mental representations and richer cognitive schemas, memory encoding, retention and retrieval, and learning (Madan & Singhal, 2012; Zacharia et al., 2012). Mental imagery is a fundamental key element for understanding and learning of science in students (Leutner, Leopold, & Sumfleth, 2009). The explicit connections between experiences and representations as well as the high level of familiarity of the scientific concepts enhanced children's learning (Enyedy, Danish, Delacruz, & Kumar, 2012). The dynamic imagery arising from the multimodal representations and use of analogies during science learning is consistent with the 'embodied cognition' notion, advocating that people learn from the interaction of their body with their physical environment (Gallagher, 2005; Wilson, 2002). Engaging preschool children's cognitive and motor skills is pivotal for their future development (Lu & Montague, 2016). Strong empirical evidence attests the positive associations of physical activity and exercise on cognition and academic achievement during childhood (Álvarez-Bueno et al., 2016; Hillman & Biggan, in press; Khan & Hillman, 2014). The fact that children in the nonintegrated physical activity condition had higher learning outcomes than the control condition provides proof in favour of this argument (Hypothesis 2).

Two previous studies conducted in preschool children, utilizing the physiological benefits of physical activity combined with the attributes from embodied learning, and incorporating short interventions of 10–20 minutes weekly with combined physical and cognitive activities during instruction in different learning domains, replicate the main findings found here (Mavilidi et al., 2015, 2016). Mavilidi et al. (2015) targeted foreign language vocabulary learning conducted 15–20 minutes, twice per week for 4 weeks, when children were randomly assigned to four conditions: In the integrated condition, they performed physical activities related to the meaning of the words (e.g. dancing for the word 'dance'). In the nonintegrated condition, they were engaged in physical activities irrelevant to the meaning of the word (i.e. running for each word). In the gesturing condition, the children remained seated and gestured related to the meaning of the word (e.g. rhythmic hand movements for the word 'dance'). Finally, in the conventional condition, the children remained seated and repeated the words with no movements involved. The results showed that the children in the integrated condition had the highest scores on free-recall and cued-recall tests and that the children in both the nonintegrated and gesturing conditions outperformed the children in the conventional condition on the cued-recall test. The children's physical activity levels were equal in the physical activity groups (integrated and nonintegrated conditions) but higher compared with the gesturing and conventional conditions. Finally, in Mavilidi et al. (2016), the children attended three learning sessions of 10 minutes per day while learning geography (i.e. the continents and characteristics animals living in each continent) and were randomly assigned to three experimental conditions: In the integrated condition, physical activities were linked with the information to be learned such as hopping like a kangaroo from Oceania; the nonintegrated condition, in which physical activities were irrelevant to the information such as running around the map; and a control condition, where the children remained seated and listened to the information to be learned. The physical activity groups outperformed the control condition, whereas the children in the nonintegrated condition were more physically active than the children in the integrated and in the control conditions. Both studies suggested that active learning through the integration of physical activities with academic content has the potential to enhance preschool children's learning performance, with effects found when instruction was conducted in groups (Mavilidi et al., 2015) as well as individually (Mavilidi et al., 2016).

In addition, although we were expecting the children in the physical activity groups (integrated and nonintegrated conditions) to be involved in the same levels of physical activity, this was not found to hold true in this case. This study corroborates the findings of physical activity measurements from Mavilidi et al. (2016) and can be attributed to the type and nature of the learning task. The children in the nonintegrated condition in both studies had to run around (the planets and the map respectively) and consequently covered a greater distance compared with the children in the integrated condition. It is possible that higher physical activity intensity levels for the integrated condition would contribute to even higher learning scores, but this needs to be examined in future research.

Nevertheless, it is likely that the children did not enjoy the physical activity aspect unrelated to the task as they evaluated it the same as in the control condition, in which the children remained seated and observed the planets. Conversely, they showed higher levels of enjoyment in the integrated condition as they evaluated it higher than the control condition, partly confirming Hypothesis 3. Existing literature supports that collaborative learning (Shoval, 2011) and classroom based-physical activity programmes (Vazou & Smiley-Oyen, 2014) can enhance children's motivation and enjoyment.

In summary, this is the first experiment to include objective measurements of both physical activity and learning outcomes in preschool children's science learning. It adds to the existing body of research indicating how physical activity interventions can positively affect cognitive functioning and academic performance in children (Diamond, 2015; Diamond & Lee, 2011; Schmidt, Benzing, & Kamer, 2016; Vazou, Pesce, Lakes, & Smiley-Oyen, in press). The effects are more pronounced when these interventions include cognitively engaging activities during learning. In the present study, the children in the integrated condition seemed to have benefited from the combined embodied and physical activity effects. In addition to this, the children might have benefited not only from making movements but also from observing others' movements. In accordance with research on the 'mirror neuron system', looking at others' actions may activate the same neurons related to these actions in the motor cortex (Rizzolatti & Craighero, 2004). The mirroring capacity can be transferred during learning of cognitive tasks including a motor component (Paas & Sweller, 2012; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009). Future research should shed light on the effects of performing and observing physical activities on learning occurring in groups and/or individual sessions as well as isolating the effects of embodiment and physical activity, motivation, and cooperative learning.

Future research is also recommended to investigate the effectiveness and efficacy of classroom-based physical activity programmes with different target groups such as adolescents and different learning contents related to science, as well as the generalizability of outcomes to more complex cognitive tasks. In addition, intervention studies at larger scale and for more prolonged periods would be needed to capture the long-term effects of physical activity, related to the possible changes in body mass index and physical fitness, on preschool children's cognition and learning, allowing us to be more conclusive in an area of research which is currently scarce. So far, it has been shown that single bouts of physical activity (acute exercise) can provoke physiological arousal facilitating the available attentional resources and engagement of cognitive functioning, whereas multiple bouts (chronic exercise) alternate morphologically brain regions responsible for learning (Best, 2010; Brisswalter, Collardeau, & René, 2002; Tomporowski et al., 2008).

Finally, this study took into account the nested nature of data as well as participants' demographics characteristics. Although no significant differences were found among the conditions, a stricter criterion during randomization would be advisable in future research to control for potential confounders.

In conclusion, this study places science learning in early childhood—an area where there has been little research—at the centre of attention. However, children usually face challenges with deeper understanding of concepts of science. Best et al. (2006) assessed the knowledge of children from ages 4 to 8 years old on science and more specifically on their knowledge about the concept of eclipse and entities related to space (i.e. sun, moon, earth, and planets). Their aim was to examine what children were able to understand about science and at what level their mental representations of space correspond with those of adults. It was found that children were able to acquire new words or concepts as abstract as space but not as accurately as adults. Even though children obtained knowledge about solar eclipse, the concept of lunar eclipse was more difficult for them. Nevertheless, children's interest and knowledge in science commence well before formal schooling. This study suggests a promising and entertaining way to promote the acquisition of fundamental concepts during science learning (i.e. the solar system), knowledge that is required by young children when entering school (*Benchmarks*; American Association for the Advancement of Science, 1994; Plummer, 2009). Early exposure and familiarization to the contents of science are the foundational basis for learning (Trundle, 2015), rendering them as the backbone for science, technology, engineering, and mathematics learning and future related careers.

Overall, the present study suggests a promising instructional approach that has the potential to offer significant physical, psychological, and cognitive gains. Notable changes were detected only within a short intervention of 1 hour in total. We think that longer periods will offer even more pervasive results, but this needs to be confirmed in future research. This innovative method is easy to implement, requires little additional resources or equipment, and can be adjusted to teachers' restrictions and demands during daily routines. At the same time, it can foster academic achievement through higher engagement and performance, while compensating for the loss in academic time that is characteristic for normal physical activity lessons that are not integrated with learning (Sallis et al., 1997; Ward et al., 2006). Notably, taking into account the increment of overweight preschool children (Ogden et al., 2006), who are less active in the childcare centres compared with their normal counterparts (Trost, Sirard, Dowda, Pfeiffer, & Pate, 2003), initiating physical activity into classroom-based programmes would result in a concomitant increase in children's daily physical activity intensity levels. In turn, infusing physical activity with learning tasks would bring preschool children closer to the suggested 3 hours per day of physical activity recommendations (Australian Government Department of Health, 2014; Tremblay et al., 2012), leading to a healthier lifestyle and well-being in the long term.

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