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Immediate and delayed effects of integrating physical activity into preschool children's learning of numeracy skills

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ABSTRACT

A cluster-randomized controlled trial was conducted to examine the effects of a 4-week program that integrated movements into cognitive tasks related to numerical skills. Participants ($N = 120$, $M_{age} = 4.70$ years, $SD = 0.49$; 57 girls) were assigned to one of the following four conditions: performing integrated physical activity (task relevant), performing nonintegrated physical activity (task nonrelevant), observing integrated physical activity, or conventional sedentary teaching (without performing or observing physical activity). Results showed that children who performed task-relevant integrated physical activity performed better than children in all other conditions. In addition, children who performed physical activity, either integrated or nonintegrated, reported higher scores for enjoyment of the instructional method than the two sedentary learning conditions. Implications for educational theory and practice are discussed.

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Introduction

The power of human movements during the first stages of young children's learning was addressed early by the developmental theories of Piaget (1968; concept of reflective abstraction) and Vygotsky (1967; make-believe play and imagination). Researchers within the field of educational psychology have been showing increased research interest in examining effects of gestures or subtle motor movements on learning. In addition, recent research attests to the physiological, cognitive, and academic benefits of physical activity in childhood learning activities (Sibley & Etnier, 2003; Tomporowski, Davis, Miller, & Naglieri, 2008). However, this research mostly targeted primary school children (e.g., math; Mahar, 2011; Ruiter, Loyens, & Paas, 2015). Only a few studies have been conducted during early childhood in different domains such as language (Mavilidi, Okely, Chandler, Cliff, & Paas, 2015), geography (Mavilidi, Okely, Chandler, & Paas, 2016), and science (Donnelly & Lambourne, 2011; Mavilidi, Okely, Chandler, & Paas, 2017). This study investigated the effects of integrated physical and cognitive activities on preschool children's learning of numeracy skills.

The theoretical frameworks of embodied and grounded cognition lay the foundation for research into the relation between the human motor system and cognition. These approaches assume that perception and action are closely intertwined (Barsalou, 2003). According to Wilson (2002), people learn from the interaction between their body and the physical environment. It is argued that cognitive processes are grounded in action and perception, whereas mental representations are grounded in different modalities (i.e., perceptual, motor, verbal, visual, auditory; Barsalou, 2008). Body, language, and the external resources from the environment can contribute to the construction of conceptual maps and foster the transition from perceptual facts to symbolic representations (Vitale, Swart, & Black, 2014). In conjunction with the theoretical framework of embodied cognition, the evolutionary perspective of cognitive load theory recognizes the significant role of the human motor system in working memory capacity during complex learning (Paas & Sweller, 2012). According to this perspective, humans have evolved to effortlessly acquire biologically primary knowledge such as human movement and speaking one's native language. This means that this type of knowledge does not impose a load on working memory and can be acquired automatically without formal instruction. In contrast, we have not evolved to effortlessly acquire biologically secondary knowledge such as reading and mathematics. Based on these ideas, Paas and Sweller (2012) argued that human movement as a form of primary biological knowledge can be used to assist the learning of mathematics as a form of biologically secondary knowledge. In line with these ideas, research has shown that connecting action and perception during instruction can be a way to promote memory consolidation, retrieval, and long-lasting learning (Barsalou, Simmons, Barbey, & Wilson, 2003; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Madan & Singhal, 2012; Paas & Sweller, 2012; Ping & Goldin-Meadow, 2010).

There is growing evidence that some aspects of mathematical knowledge can be enhanced from the interactions with the physical, social, cultural, and semiotic worlds (Alibali & Nathan, 2012). Linking abstract mathematical knowledge with sensorimotor metaphors, stemming from the human body and its imaginary motion (i.e., grounding actions), can help in transforming it into tangible events or situations with which young children are familiar. For example, numbers placed in a number line can be seen as an ordered path of magnitudes that one can move along (see, e.g., Núñez & Marghetis, 2015). The studies of Fischer, Moeller, Bientzle, Cress, and Nuerk (2011) and Link, Moeller, Huber, Fischer, and Nuerk (2013) found improvements in young children's counting principles from 0 to 10 ($p < .05$, $ES = .68$, with no effects for the 0–20 scale) and spatial numerical representation ($p < .02$, $ES = .89$, with no effects for single-digit and two-digit sums, nonsymbolic number comparison, and place value understanding) after walking on a number line. In the first study, kindergarten children either made steps to the left for smaller numbers and to the right for larger ones while walking on a dance mat or performed the same numerical task without the movements on a tablet PC. In the second study, first-grade children either performed task-specific full-body movements while walking on a number line or received number line training without the body experiences. Finally, Ruiter et al. (2015) examined first-grade children's learning of two-digit numbers by making steps on a ruler mounted across the floor either while watching their movements in a mirror (or not) or in a control condition without movements. In the movement conditions, children made small, medium, and large