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Behavioral self-regulation and executive function both predict visuomotor skills and early academic achievement☆

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ABSTRACT

The present study explored direct and interactive effects between behavioral self-regulation (SR) and two measures of executive function (EF, inhibitory control and working memory), with a fine motor measure tapping visuomotor skills (VMS) in a sample of 127 prekindergarten and kindergarten children. It also examined the relative contribution of behavioral SR, EF, and VMS skills for concurrent academic achievement. Results indicated that a measure of working memory (WJ-Working Memory) and a measure of behavioral SR (Head–Toes–Knees–Shoulders task; HTKS) were directly related to VMS. Differential relations were also examined for prekindergarten and kindergarten children. Results revealed a significant interaction between age and inhibitory control (Day–Night), and an interaction at a trend level between age and working memory suggesting both tasks are more related to VMS skills for younger children. Results also indicated that behavioral SR, EF, and VMS skills were differentially related to the three achievement outcomes. Both behavioral SR and VMS were significantly related to math, behavioral SR, EF, and VMS were significantly related to emergent literacy, and behavioral SR and EF were related to vocabulary scores. Results point to significant relations between behavioral SR and EF with VMS, and how each is related to early academic achievement in preschool and kindergarten.

Introduction

As researchers examine the cognitive and behavioral skills involved in early academic achievement, new research suggests that components of fine motor skills play an important role in facilitating the learning process. Fine motor skills can be delineated into tasks involving motor control (e.g., tracing), or tasks that integrate motor and spatial abilities (visuomotor skills, e.g., copying a geometric shape) (Carlson, Rowe, & Curby, 2013). Visuomotor skills (VMS) are related to both math and emergent literacy (Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010), and are emerging as discrete skills involved in early learning (Cameron et al., 2012). Although VMS are a unique predictor of early achievement, it is not fully understood why these skills are linked to academic success, or if components of cognition enhance or predict VMS. Executive function (EF) is a set of cognitive processes involved in higher-level, goal-directed processing consistently linked to early achievement (Blair & Razza, 2007), which manifests as behavioral self-regulation (SR) (McClelland et al., 2007), and both could play a role in VMS. Indeed, the link between behavioral SR and EF with VMS is supported by behavioral (Decker, Englund, Carboni, & Brooks, 2011), brain (Diamond, 2000), and cognitive research (Boncoddo, Dixon, & Kelley, 2010). Yet studies looking at direct connections between behavioral SR and EF with VMS have not consistently demonstrated strong connections (Cameron et al., 2012; Grissmer et al., 2010).

Additionally, little research has explored relations between the different dimensions that form the EF construct (i.e., working memory, cognitive flexibility, inhibitory control; Garon, Bryson, & Smith, 2008) with VMS, or explored the relative contribution of the different dimensions of EF relative to VMS concurrently with academic achievement. Given that VMS are a strong predictor of early academic outcomes (Cameron et al., 2012; Grissmer et al., 2010; Son & Meisels, 2006), it is also possible that different dimensions of EF (e.g., working memory) could differentially relate to achievement when assessed relative to VMS. For example, tasks that integrate motor and visual processes are highly related to the development of literacy and math skills (Puranik & Lonigan, 2012; Zebian, 2005), with the connection between literacy, numeracy, and VMS possibly

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augmented through writing numbers and letters. As such, it is possible that when VMS are assessed with working memory, they might be more strongly related to emergent literacy and math. In the present paper, utilizing a concurrent research design, we explored direct connections between behavioral SR and EF with VMS, and assessed if behavioral SR and EF are differentially related to VMS for prekindergarten- and kindergarten-age children. We also examined if behavioral SR, EF, and VMS differentially relate to academic achievement in prekindergarten and kindergarten children.

Visuomotor skills and academic achievement

It is estimated that preschoolers and kindergarteners spend between 27% and 66% of the school day working on some form of fine motor activity (Marr, Cermak, Cohn, & Henderson, 2003), which makes fine motor skills an important aspect of early school readiness (Bredekamp & Copple, 1997; Johnson, Gallagher, Cook, & Wong, 1995; Lillard, 2005). Fine motor measures usually examine some level of visual motor integration, spatial organization, manual control, or perceptual ability, and often ask the child to trace, manipulate blocks, or copy and create an external image. In the present study, we measured children's ability to copy a series of geometrics shapes, and define fine motor skills as visuomotor skills (VMS), which incorporates visual spatial processing, movement within small muscle systems, and hand–eye coordination.

The idea of *learning to learn* (Adolph, 2005) suggests early learning is centered around the motor system, with brain systems involved in posture, gripping, vision, and motor control acting in concert. As the child adapts to changing environmental demands, both cognitive and motor skills develop together. The coordination of reaching, grasping, and walking must take place to produce solutions to novel locomotor challenges (Adolph, 2008), with this motor flexibility acting as the earliest form of learning and setting the stage for higher level processing (Bushnell & Boudreau, 1993). Anatomical connections between brain systems involved in balance and EF (Diamond, 2000) support the early link between gross motor movement and learning. Further, the theory of *embodied cognition* links the body and motor system to language comprehension (Fischer & Zwaan, 2008), memory (Barsalou, 1999), problem solving (Boncoddo et al., 2010), and spatial processing (Moreau, 2013a).

Consistent with the above framework, evidence shows spatial processing and EF can be hindered by physically restraining the arm and hand (Moreau, 2013a, 2013b). This is not to say that the physical body is the only system involved in spatial processing and EF, but that fine motor movements could play a role in this process. Further evidence for a link between the body and visuomotor skills with academic achievement is found in work linking visual–spatial working memory to math and literacy (St Clair-Thompson & Gathercole, 2006), and overlapping brain networks to both visuospatial and numerical processing (Hubbard, Piazza, Pinel, & Dehaene, 2005). Visuospatial processes are also spontaneously engaged when individuals are actively processing arithmetic and numerical information (e.g., Dehaene, 1992).

Aside from spatial processing, at the classroom level, children with better VMS are more likely to show a faster rate of automaticity, allowing for an easier translation of letters and numbers to paper. As skills become automatized, activity moves from cortical to sub-cortical regions, which frees up cognitive resources (Floyer-Lea & Matthews, 2004). For children with better VMS, less conscious attention would be focused on scripting letters and numbers, allowing for cognitive energy to be distributed to connecting figures and sounds, decoding words, and understanding mathematical concepts. Consequently, problems integrating visual perception, posture, motor control, and VMS are often reflected in academic difficulties (Alloway & Archibald, 2008; American Psychiatric Association, 2010).

Measures of visual-motor coordination (e.g., tracing tasks), VMS, and gross motor skills have been assessed in relation to achievement (Carlson et al., 2013; McPhillips & Jordan-Black, 2007), with a preponderance of work showing VMS tasks, compared with tracing and gross motor measures, are a better gauge of academic outcomes (Bart, Hajami, & Bar-Haim, 2007; Cameron et al., 2012; Carlson et al., 2013). This is demonstrated by studies examining longitudinal connections between VMS and achievement, which show that VMS in kindergarten predict third grade literacy (Taylor, 1999), math, and spelling scores (McPhillips & Jordan-Black, 2007). Aggregating three longitudinal data sets, Grissmer et al. (2010) showed that VMS at kindergarten entrance predicted third and fifth grade literacy and math achievement.

In a recent study by Cameron et al. (2012), VMS measured prior to entering kindergarten significantly predicted fall letter-word identification, reading comprehension, and sound awareness, as well as improvement in these scores from fall to spring. Finally, in a cross-sectional sample between the ages of 5 and 18, strong VMS related to higher math and writing scores after controlling for visual-motor coordination (i.e., tracing) (Carlson et al., 2013). The significant connections between VMS and achievement highlight the need to understand what other skills relate to VMS.

Behavioral self-regulation, executive function, and achievement

Executive function (EF) is a set of cognitive processes involved in higher-level, goal-directed processing that has been consistently linked to academic success (Duncan et al., 2007; McClelland & Cameron, 2011). Although the processes that comprise the EF construct are highly interrelated, they are often delineated into distinct components (Hughes, 1998; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). This framework, known as the *unity and diversity construct of EF* (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), incorporates updating (i.e., working memory), cognitive flexibility, and inhibitory control (Best & Miller, 2010). As EF is involved in the regulation of both thought and action (Koziol, Budding, & Chidekel, 2012), the construct of behavioral self-regulation (SR) is viewed as the behavioral manifestation of EF (Barkley, 1997, 2011; McClelland & Cameron, 2012). In general, EF is required to modify overt behavior and this can be assessed through measures of behavioral SR.

Within the classroom, a child must seamlessly integrate behavioral SR and EF as they shift between tasks, interact with peers, and follow directions. For example, as a child moves from free play to teacher-led instruction, they must inhibit the prepotent tendency to continue playing, move to the new activity, listen for directions, and hold in mind and follow the teacher's instructions. The prefrontal cortex is a critical brain region for carrying out these actions (Arnsten & Li, 2005; Duncan & Owen, 2000), and shows heightened development between ages two and five (Posner, Rothbart, Sheese, & Voelker, 2012; Rothbart, Ellis, Rueda, & Posner, 2003). This makes the prekindergarten and kindergarten years a salient time for examining behavioral SR and EF.

Studies looking at connections between behavioral SR and EF with achievement in prekindergarten populations consistently show both are related to higher academic outcomes. For example, inhibition is a key factor involved in academic learning (Borella, Carretti, & Pelegrina, 2010; Bull & Scerif, 2001; D'Amico & Passolunghi, 2009). In one study, Bull and Scerif (2001) examined different components of EF as predictors of mathematics ability, and found that poor inhibitory control was the key component related to lower math scores at age 7. Other work finds similar effects with measures of attention, which predicts early (Duncan et al., 2007) and long-term academic success (McClelland, Acock, Piccinin, Rhea, & Stallings, 2013).

At the same time, a child's ability to shift focus between tasks and inhibit inappropriate actions is a key component of early