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The relationship between spatial working memory precision and attention and inhibitory control in young children

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ABSTRACT

Spatial working memory (SWM) and executive functions, including attention, inhibition and working memory, are important for children's well-being, educational attainment, and social relationships (Bull & Scerif, 2001; Posner, 2012; Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006). The purpose of the current study is to examine the relationship between attention and inhibition, and a SWM task in 4–8-year-old children. The SWM task measured children's ability to remember the location of a target on a blank screen both with and without a distractor present during the delay. We conducted a secondary data analysis of this task from two previous studies (Author Blinded for Review, 2014; Authors Blinded for Review, 2017). Multilevel models showed that for younger children, faster reaction time on an attention task was related to errors in the SWM task that were more similar to older children. In addition, children whose parents indicated they had higher inhibitory control inhibited distractors more than other children. Overall, the findings demonstrate that children with greater attention and inhibition abilities also had greater SWM abilities.

1. Introduction

Throughout childhood, children's executive functions, including working memory, attention, and inhibition, become more sophisticated (Bull & Scerif, 2001; Posner, 2012; Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006). Working memory, specifically, is important for children's everyday functioning, and deficits in working memory predict inattentive and off-task behavior in a child's everyday environment (Gathercole, Durling, Evans, Jeffcock, & Stone, 2008; Lui & Tannock, 2007). Spatial working memory (SWM), the focus of this study, is specifically related to pre-mathematical counting skills in preschoolers (Kyttälä, Aunio, Lehto, Van Luit, & Hautamäki, 2003), and math abilities in school-age children (Holmes, Adams, & Hamilton, 2008), and adults (Clearman, Klinger, & Szűcs, 2017). Despite the importance of SWM, we do not have a good understanding of the relationship between SWM and other executive functions, such as attention and inhibition, early in development.

1.1. Development of spatial working memory

Research shows that the precision of SWM increases with age (Huttenlocher, Newcombe, & Sandberg, 1994; Schutte & Spencer, 2009). However, the accuracy of a location held in SWM is subject to errors that demonstrate systematic biases known as geometric

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biases, which change direction over development. For example, when children are asked to remember the location of an object in a homogeneous space (e.g., a computer screen), they rely on reference axes such as the edges of the screen and the perceived midline symmetry axis of the space. The memory responses of younger children tend to be biased toward the center of the space, or toward the midline symmetry axis. In contrast, the responses of older children tend to be biased away from the center of the space (Huttenlocher et al., 1994; Schutte & Spencer, 2009). The transition from attraction toward the center to repulsion from the center occurs between 3 and 6 years of age (Huttenlocher et al., 1994) with the bias away increasing in early development (Schutte & Spencer, 2009) followed by an apparent decrease into adulthood (Spencer & Hund, 2002, Spencer & Hund, 2003).

SWM precision is also influenced by the homogeneity of the space, including whether any distractors are present during the delay (e.g., Schutte, Keiser, & Beattie, 2017), and the attentional demands of the task, including whether distractors are supposed to be attended or ignored (e.g., Johnson & Spencer, 2016). The effects of these variables may change over development. For example, Schutte et al. (2017) found that when 6-year-olds were instructed to ignore a distractor presented during the delay of a spatial recall task, they were biased away from distractors that were near the target location. In contrast, 3-year-olds were biased toward some ignored distractors. Thus, distractors appear to create biases similar to those created by reference axes, in that younger children show attraction, while older children show repulsion. However, the effect of a distractor interacts with the location of reference axes such as the midline of the space (Schutte et al., 2017). Specifically, when distractor and reference axis biases were in competition, i.e., repulsion from the reference axis and repulsion from the distractor were in opposite directions, the influence of the distractor on errors was larger than when the repulsion from the reference axis and repulsion from the distractor were in the same direction.

1.2. Connection between SWM and other executive functions

Most developmental research examining developmental changes in SWM precision and bias fails to examine the role of developmental changes in other cognitive abilities, such as attention and inhibition, in the development of SWM. Attention, inhibition, and working memory are each cognitive processes that are involved in executive functions, although researchers disagree on how exactly to define executive functions (for a review of definitions, see Barkley, 2012). These processes involve the prefrontal cortex (Pribram, 1973) and are involved in goal-directed behavior (Gioia, Isquith, Guy, & Kenworthy, 2000). Perhaps most 3-year-olds in Schutte et al. (2017) unintentionally shifted their attention to the distractor location while the 6-year-olds successfully inhibited the distractor, resulting in a bias toward the distractor for the 3-year-olds and a bias away for the 6-year-olds. If this is the case, measures of attention and inhibition in young children should be related to the influence of distractors on SWM performance. Despite the lack of research directly examining the relationship between SWM and other executive functions in early development, studies of the development of attention and inhibition suggest that their development may be related to developmental changes in SWM. The development of attention and inhibition, and their relationship to SWM are each discussed below.

1.2.1. Attention across development

Attention, defined as "focusing of sensory, motor and/or mental resources on aspects of the environment that requires knowledge" (Sheridan, 2007, p. 16), begins to develop in infancy and becomes more sophisticated throughout childhood. Even very young infants have the ability to be selective with their attention, while other aspects, including the ability to shift attention develop later in childhood (see Ruff and Rothbart, 1996, for a review). Research examining the development of sustained attention has shown that it develops rapidly between the ages of 5–9 years of age and then levels off after the age of 10 (Betts, Mckay, Maruff, & Anderson, 2006). After the age of 10 children show only small changes in their sustained attention abilities (Betts et al., 2006). One of the most commonly used behavioral measures of sustained attention is the Continuous Performance Task (CPT). Research examining the use of the CPT in school-aged children (6–13-year-olds) found that sustained attention continues to develop during the primary school years, in particular between 6–12 years of age (Lin, Hsiao, & Chen, 1999).

Previous research suggests that there may be a central attention system that plays a role in the expression of other executive functioning processes (Garon, Bryson, & Smith, 2008; Rothbart & Posner, 2001). Garon et al. (2008) propose that improvement in executive functioning is due to the development of the attention system, which connects with other brain areas that underlie executive functioning processes (i.e. working memory and inhibition). If this proposal is accurate, measures of attention should relate to measures of different executive functions (e.g., working memory) across development.

1.2.2. SWM and attention in adults

Behavioral and neuroimaging research has found a strong link between spatial attention and SWM in adults. In adults, attention influences both the encoding and maintenance of locations in SWM (see Awh, Vogel, & Oh, 2006, for a review). Adults use spatial selective attention to select a location in space in order to encode stimuli at that location. Additionally, Awh et al. propose that spatial selective attention acts as a rehearsal mechanism in SWM, thus influencing maintenance in SWM (Awh & Jonides, 2001; Awh, Jonides, & Reuter-Lorenz, 1998). Specifically, when adults move their attention from the memorized location in order to complete a secondary task, memory accuracy decreases (Awh et al., 1998) and memory responses are biased toward the intermediary attended location (Johnson & Spencer, 2016).

1.2.3. SWM and attention in children

Given that attention develops throughout childhood, there is a lack of developmental research examining relationships between SWM and attention described above for adults. Espy and Bull (2005) suggest that young children's attention may play an important role in their ability to encode information in working memory. In examining two tasks that required attentional control, they find that