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Brief Report

Visuospatial bootstrapping: Implicit binding of verbal working memory to visuospatial representations in children and adults

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When participants carry out visually presented digit serial recall, their performance is better if they are given the opportunity to encode extra visuospatial information at encoding—a phenomenon that has been termed *visuospatial bootstrapping*. This bootstrapping is the result of integration of information from different modality-specific short-term memory systems and visuospatial knowledge in long term memory, and it can be understood in the context of recent models of working memory that address multimodal binding (e.g., models incorporating an *episodic buffer*). Here we report a cross-sectional developmental study that demonstrated visuospatial bootstrapping in adults ($n = 18$) and 9-year-old children ($n = 15$) but not in 6-year-old children ($n = 18$). This is the first developmental study addressing visuospatial bootstrapping, and results demonstrate that the developmental trajectory of bootstrapping is different from that of basic verbal and visuospatial working memory. This pattern suggests that bootstrapping (and hence integrative functions such as those associated with the episodic buffer) emerge independent of the development of basic working memory slave systems during childhood.

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Introduction

There is considerable evidence that verbal and spatial information is handled by different short-term memory processes (see Baddeley, 2000). This sits alongside considerable evidence of substantial shared variance within measures that involve the processing, rather than the simple storage, of remembered items (Engle, Tuholski, Laughlin, & Conway, 1999). Evidence of both types underlies the development of theoretical approaches that clearly differentiate process-dependent memory systems from storage systems where information is stored but not manipulated. One such approach is the *working memory model* (Baddeley, 1986; Baddeley & Hitch, 1974), which proposed the interaction of a *central executive* (CE) processing component alongside modality-specific passive storage systems (the *phonological loop* and *visuospatial sketchpad*). An alternative model (Engle, 2010; Engle et al., 1999) proposed that storage functions labeled as *short-term memory* (STM) may be supported by distinct subsystems, whereas processing functions labeled as *working memory* (WM) require a common integrated set of processes associated with a substantial shared variance. Even theoretical approaches that deemphasize modality-specific systems (Cowan, 2005) still accommodate the idea that basic storage processes may be differentiable on the basis of task demands.

Despite this, STM subsystems are not entirely discrete and information stored in separate modalities can be linked (Mate, Allen, & Baqués, 2012: Morey & Cowan, 2004, 2005; see Baddeley, 2000, for a review of earlier evidence). Recently, the integration of visuospatial, verbal, and long-term memory has been demonstrated in verbal serial recall. When to-be-remembered digits were presented in a familiar visuospatial array—the standard numeric keyboard used in mobile telephones—memory was facilitated compared with when digits were presented in a single location (Darling & Havelka, 2010). Participants were asked to attend to only a single stimulus dimension (digit serial recall), but the performance improvement associated with keypad presentation indicated that they were able to extract visuospatial information and integrate it with the verbal material. Hence, this pattern was described as *visuospatial bootstrapping* (Darling & Havelka, 2010) because verbal memory performance was *bootstrapped* by the integration of redundant visuospatial information that was present in the keypad condition and not in the single item condition. A subsequent study has replicated visuospatial bootstrapping (Darling, Allen, Havelka, Campbell, & Rattray, 2012), also showing that the availability of a compatible representation in long-term memory (LTM) is necessary for observing bootstrapping. Visuospatial bootstrapping represents an effect where nonverbal memory processes interact with verbal memory; a parallel result has recently been reported, where visuospatial memory is differentially impaired by concrete and abstract verbal load (Mate et al., 2012). Taken together, these patterns are inconsistent with the possibility that WM subsystems are fully independent of each other. They also suggest that interactions between WM systems take place on an implicit level—or at least without explicit instruction to combine information from different sources.

The *episodic buffer* (Baddeley, 2000) was proposed as an additional WM component capable of maintaining cross-modality bindings between information in LTM and STM, with a role in the encoding of specific episodes. Unlike the CE and other theoretical mechanisms targeted at understanding how information in WM is integrated (e.g., the focus of attention described by Cowan, 2005), the episodic buffer is now thought to require neither executive nor attentional resources to function, instead operating in an efficient, automatic, and rule-governed manner (Baddeley, Allen, & Hitch, 2011). Given this, it seems plausible that the potentially implicit visuospatial bootstrapping data might be explained with reference to the episodic buffer (Darling et al., 2012).

Aside from the episodic buffer model, there are alternative accounts of WM that can potentially offer a theoretical account of visuospatial bootstrapping. Unsworth and Engle (2007) proposed that effective WM performance entails maintenance in primary memory alongside effective search of secondary memory, and it is plausible that the bootstrapping effect occurs because keypad displays facilitate this search of secondary memory due to the provision of additional cues. There is also robust evidence that reconstructive processes facilitate temporary memory (Cowan et al., 2003; Towse, Cowan, Hitch, & Horton, 2008; Towse, Hitch, Horton, & Harvey, 2010). Given that WM for spatial configurations is certainly affected by aspects of long-term spatial memory (Brown & Wesley, 2013), it is plausible that richer spatial arrays at presentation lead to more effective reconstructions.