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Developmental and individual differences in the precision of visuospatial memory

Ioannis Sarigiannidis[a], Gemma Crickmore[b], Duncan E. Astle[b,*]

[a] Department of Education, University of Cambridge, United Kingdom
[b] Medical Research Council, Cognition and Brain Sciences Unit, Cambridge, United Kingdom

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ABSTRACT

Our ability to retain visuospatial information over brief periods of time is severely limited and develops gradually. In childhood, visuospatial short-term and working memory are typically indexed using span-based measures. However, whilst these standardized measures have been successful in characterizing developmental and individual differences, each individual trial only provides a binary measure of a child's performance—they are either correct or incorrect. Here we used a novel continuous report paradigm, in combination with probabilistic modeling, to explore developmental and individual differences in how likely children were to recall memoranda, and how precisely they could report them. Taking this approach revealed a number of novel findings: (i) a concurrent processing demand negatively impacted upon both of these parameters, increasing the guessing rate and making children less precise; (ii) older children (aged 10–12, $N = 20$) were significantly less likely to guess, but when they did remember the target were no more precise in reporting it than younger children (aged 7–9, $N = 20$); (iii) children's performance on standardized short-term and working memory tasks was significantly associated with both the guessing likelihood, and the precision of target responding, on the continuous report task. In short, we show that continuous report paradigms can offer interesting insight into processes that underlie developmental and individual differences in visuospatial memory in childhood.

1. Introduction

Our ability to manage and adapt to new and complex situations relies on our capacity to hold in mind small amounts of relevant information for brief periods. Depending upon the context, it may be necessary to hold in mind novel visuospatial or verbal information, for use in some ongoing task. In typically and atypically developing populations this short-term storage capacity is usually measured using span-based measures, with children attempting to maintain increasingly long sequences of items. Sometimes this maintenance can be alongside a concurrent processing (termed working memory, WM) or in isolation (short-term memory, STM). Performance on each trial is coded as correct or incorrect, and the span length is gradually increased until the child's average performance falls below a certain criterion. Performance up to the discontinuation point is summed to give a measure of the child's capacity, which can be expressed either as raw or age-standardized scores. Performance on tasks that tap STM and WM abilities varies markedly across children, with there being both substantial developmental and individual differences in capacity in childhood.

* Corresponding author at: MRC Cognition and Brain Sciences Unit, 15 Chaucer Road, Cambridge CB2 7EF, United Kingdom.
E-mail address: duncan.astle@mrc-cbu.cam.ac.uk (D.E. Astle).

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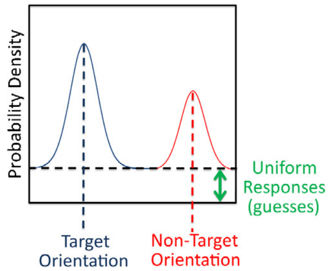

Fig. 1. A depiction of the mixture of possible responses that could be observed with a continuous report task (e.g., remembered and reporting line orientations). The blue distribution indicates a proportion of responses that across trials are clustered around the correct target orientation. The red distribution shows the proportion of responses that are clustered around the correct non-target orientation. The green distribution corresponds to a uniform distribution, which represents the proportion of trials upon which subjects produce a random guess.

There are many underlying mechanisms that might drive both developmental improvements in visuospatial STM/WM performance and the large degree of variability across children of the same age. One possibility is that poorer scores, either due to immaturity or individual differences, stem from low capacity per se. That is, what varies across children is the quantity of items that can be maintained simultaneously (Pascual-Leone, 1970). Alternatively, these differences could be underpinned by variability in the quality with which children can maintain items. Some children may be able to maintain items more precisely in memory (Burnett Heyes, Zokaei, van der Staaij, Bays, & Husain, 2012), perhaps reducing the extent to which items interfere with one another or mitigating the impact of decay. A final mechanism that might drive these differences is the extent to which children confuse the order/location of the items that they are storing in memory, leading to a misbinding error—that is, they report an incorrect, but successfully maintained item (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006). Of course, these accounts are not mutually exclusive, and differences in visuospatial memory ability across children could stem from a combination of these mechanisms. A similar set of possible mechanisms could account for the impact of concurrent processing on maintenance—it could reduce the quality of item representation, increase the likelihood of an item being lost from memory, or increase the likelihood of an incorrect item being reported. However, the methods typically used to establish capacity differences across children do not enable us to tease apart these potentially separate underlying component processes. This is because each trial only provides a single binary score that essentially combines all of these potentially separate parameters.

In the adult literature, spurred by an on-going debate as to the nature of resource allocation within visual STM, a number of researchers have started using continuous report as a means for exploring STM processes (Bays & Husain, 2008; Wilken & Ma, 2004; Zhang & Luck, 2008). Participants are presented with memoranda that can be varied in a continuous way, such as hue (Zhang & Luck, 2008) or line orientation (Bays & Husain, 2008), and by providing participants with a means of freely recalling a cued item (for instance using a color wheel or dial, respectively). This method of free recall enables the researcher to assay the underlying content of memory using a model-based approach (e.g., Anderson & Awh, 2012; Bays, Catalao, & Husain, 2009; Bays, Gorgoraptis, Wee, Marshall, & Husain, 2011; Poliakov, Stokes, Woolrich, Mantin, & Astle, 2014). In particular, it is possible to estimate the proportion of trials upon which participants correctly retain a representation of a target item (and the precision with which they do so), those upon which they incorrectly report a non-target representation, and the proportion of trials upon which participants simply guess (Fig. 1). In short, unlike the methods typically used in developmental populations, this continuous report methodology, alongside mathematical modeling, provides the researcher with an assay of the underlying content of memory. However, to our knowledge, this has only once been applied to separate these processes in childhood (Burnett Heyes et al., 2012). Children, aged between 7 and 13, were presented with either one or three oriented bars in sequence, and after a brief delay were asked to report the orientation of one of those bars. For the first time, the authors were able to show that between the ages of 7 and 13 the precision with which items could be retained showed a linear increase. This led the authors to suggest that one possible mechanism for developmental improvements in visuospatial STM is the gradual improvement in maintenance accuracy, rather than an increase in the discrete number of items that can be maintained per se.

In this study we used a novel paradigm in which children were presented with to-be-remembered bars in sequence. Following a brief delay the children had to attempt to report either the exact orientation, or the mirror image of the orientation, of one of the bars in the sequence. That is, on some trials children simply maintained and reported orientations, whereas on other trials there was an additional requirement of online manipulation (mental rotation). A trial schematic can be seen in Fig. 2. Our first aim was to explore the impact of this concurrent processing on subjects' memory of the target orientation, and then to use the probabilistic modeling approach described above to explore in more detail the impact of the mental rotation on memory performance. Our second aim was to explore developmental differences on both trial types, again using the modeling to separate the potential contributions to performance improvements with age. Finally, we also collected performance measures on standardized visuospatial STM and WM tasks. This allowed use to explore how performance on our continuous performance task, and the underlying parameters produced by the modeling, would vary across children according to individual differences in visuo-spatial STM and WM capacity.