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Human short-term spatial memory: Precision predicts capacity

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ABSTRACT

Here, we aimed to determine the capacity of human short-term memory for allocentric spatial information in a real-world setting. Young adults were tested on their ability to learn, on a trial-unique basis, and remember over a 1-min interval the location(s) of 1, 3, 5, or 7 illuminating pads, among 23 pads distributed in a 4 m × 4 m arena surrounded by curtains on three sides. Participants had to walk to and touch the pads with their foot to illuminate the goal locations. In contrast to the predictions from classical slot models of working memory capacity limited to a fixed number of items, i.e., Miller's magical number 7 or Cowan's magical number 4, we found that the number of visited locations to find the goals was consistently about 1.6 times the number of goals, whereas the number of correct choices before erring and the number of error-less trials varied with memory load even when memory load was below the hypothetical memory capacity. In contrast to resource models of visual working memory, we found no evidence that memory resources were evenly distributed among unlimited numbers of items to be remembered. Instead, we found that memory

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for even one individual location was imprecise, and that memory performance for one location could be used to predict memory performance for multiple locations. Our findings are consistent with a theoretical model suggesting that the precision of the memory for individual locations might determine the capacity of human short-term memory for spatial information.

1. Introduction

Historically, two constructs have been used to describe the processing of memories over short periods: short-term memory and working memory (Baddeley, 2003; Becker & Morris, 1999; Cowan, 2008; Unsworth & Engle, 2007). Following Baddeley and Hitch's model of working memory (Baddeley & Hitch, 1974), numerous studies investigated the capacity of the so-called "visuo-spatial sketchpad". Paradigms used to study visuo-spatial working memory processes typically assess participants' abilities to remember "what" they saw (visual memory), "where" they saw it (spatial memory), or "what" they saw "where" (visuo-spatial memory). Participants are usually shown one to several stimuli on a screen or a piece of paper placed in front of them, and after a short delay (one to several seconds) are asked to recall what the specific stimulus was, or whether there was a change in the location of one of the stimuli. Estimates of visuo-spatial short-term memory capacity have typically revealed an upper limit of 4 ± 1 items (see (Cowan, 2001) for a comprehensive review and discussion of human mental storage capacity).

Other paradigms designed to evaluate visuo-spatial memory capacity assess participants' serial recall of spatial locations. Participants must repeat a previously-viewed, serially-demonstrated target sequence. Investigations assessing serial spatial memory span have implemented the Corsi block-tapping task with nine blocks (CBT; (Corsi, 1972)), or target locations presented on a screen (Avons, 2007; Fagot & De Lillo, 2011; Parmentier, Elford, & Mayberry, 2005). The length of the sequence repeated correctly represents the spatial span; immediate span for block-tapping was originally reported to be 4.9 for normal young adults (average age: 28.1 years; (Corsi, 1972)). Replications of the original task revealed an average spatial memory span around 6 ± 1 for normal controls (Berch, Krikorian, & Huha, 1998; Farrell Pagulayan, Busch, Medina, Bartok, & Krikorian, 2006). Recently, Piccardi and colleagues developed the Walking Corsi Test (WalCT), a large-scale version of the CBT (scale 1:10), in which participants have to walk and reach different locations in a real environment (Piccardi et al., 2008). Normative data in healthy young adults revealed a serial spatial memory span ranging from 5.96 to 7.37 with the CBT, and from 5.61 to 7.93 in the WalCT, depending on the delay between presentation and recall (Piccardi et al., 2013). Estimates of the serial spatial memory span are thus more in agreement with Miller's magical number 7 ± 2, as the limit of our immediate memory capacity for individual items or chunks of information (Miller, 1956).

It is important to note that, although those studies assessed visuo-spatial memory, they did not assess allocentric spatial memory. Indeed, the brain can represent object locations, whether they are real objects in the real world, or a visual array presented on a screen or a piece of paper, via distinct spatial representation systems (Banta Lavenex & Lavenex, 2009; Burgess, 2006; O'Keefe & Nadel, 1978). Over the short term, and when the observer's position is fixed in relation to a real or graphically-presented object array, egocentric (body-centered or viewpoint-dependent) coding is the most reliable, and allocentric (world-centered or viewpoint-independent) encoding unnecessary (Banta Lavenex et al., 2011). However, once the observer begins to move in the world, allocentric spatial coding becomes critical to spatial memory processing (Banta Lavenex, Colombo, Ribordy Lambert, & Lavenex, 2014; Banta Lavenex & Lavenex, 2009; Burgess, 2006; O'Keefe & Nadel, 1978). Over the years, a number of researchers have investigated human short-term visuo-spatial memory using tasks distinguishing different spatial frames of reference (Abrahams, Pickering, Polkey, & Morris, 1997; Burgess, Spiers, & Paleologou,