# Configural representations in spatial working memory

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At any given moment, people must keep track of the locations of a number of objects surrounding them to guide their movements. However, the nature of spatial representations in working memory and in particular, what information is maintained and how it is rehearsed across short time intervals, have not been systematically explored. Recently, studies of scene change detection in which people have to determine whether two consecutively presented scenes are identical, have indicated that people are sensitive to the spatial layout of objects within scenes (Simons 1996). Similarly, Jiang and colleagues (2000) have demonstrated that people incidentally encode the layout of visual objects. In the research I present, I describe studies that specifically focus on spatial representations in working memory.

One major feature of spatial representations is the degree to which locations are coded independently or whether or not relationships amongst locations are represented. If locations are coded independently, then for each location only absolute positional information is present in the representations. In other words, no relative location cues exist in the representations. Such absolute location information may be represented in the form of coordinates, such as Cartesian or polar coordinates. The alternative to the coding of locations in an independent-absolute manner is the coding of locations as part of larger configurations. With configural representations, we specifically refer to the presence of information about relative locations and the spatial relationships, from which information about the overall configuration can be easily extracted. Any claims we make that representations are configuration-based are supported by data indicating that information maintained about the configuration is above and beyond what could be deduced from the accurate absolute positional representations of each location.

Establishing a distinction between independent and configural codes for representing locations does not differentiate among the possible different ways spatial information is rehearsed. Specifically, configural codes do not suggest or necessitate that people maintain multiple locations by maintaining an image of the configuration formed by all the locations. The primary goal of the research I am presenting has been to reveal what information is available to people as they are recalling the locations. What is crucial and of interest has been whether information about the configuration can be easily extracted from the mental representations of multiple locations.

In a series of studies we employed a serial spatial recall task where participants were presented with sequential and randomly generated target locations and then they were asked to recall these locations in the order they were presented. The coordinates picked by the participants for each one of the target locations were recorded. The open-ended nature of the task allowed for the investigations of the metric properties of the representations. Specifically, from the responses, we calculated two dependent measures: distance error and angular error. Distance error was the Euclidean distance between each target location and where it was recalled to be. In order to have a measure of how well the configuration formed by the sequence of locations presented is preserved we calculated the angles between subsequent locations both in the sequence of target locations presented and in the responses participants made. Angular error was defined as the absolute difference between corresponding angles in the target set

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and in the response set.

In the first study, participants were asked to recall sequences consisting of 3, 4, 5 or 7 locations. There were significant list length effects on both distance and angular error, with error increasing at longer list lengths. For the longer list lengths (5 and 7), there were also serial position effects. The first and last positions were recalled more accurately than mid-positions in the spatial sequence. However, for shorter sequences the amount of distance error at each position was approximately equal.

In order to directly demonstrate that spatial representations preserve configuration information, we compared angular error from the participants' data to angular error calculated from simulated data. The simulated data were based on each participant's distance error and it reflected how their performance would have been if they had represented each location in absolute positional terms. Specifically, for each participant we generated data representing how performance would have been if she/he had remembered each location in a given sequence independent from locations preceding and following that particular location, but with the same amount of distance error s/he had made at that position in the sequence. Once the simulated data were generated for each participant, then angular error for the simulated data was calculated as it was from the actual responses. The angular error from each participant was then compared to the angular error from the simulated data based on his/her distance error.

If participants were remembering configurations, and not remembering the locations in an independent fashion, the angular error from participants' data would be significantly less than the angular error in the simulated data. Our analyses revealed that this was indeed the case. For shorter sequences (3 and 4), participants' angular error was significantly less than that in the simulated data, suggesting that participants were maintaining configuration information for shorter sequences. This observation was in accord with evidence from the distance error data indicating a qualitatively different pattern of errors for short (3 and 4) versus long (5 and 7) sequences. Thus, we concluded that people preserve configuration information above and beyond absolute location information in short sequences (Boduroglu and Shah 2004).

In a separate study employing the same serial spatial recall paradigm, we further investigated how sequence length and sequence complexity influence spatial recall. Some prior research suggests that complexity might influence memory for spatial information. For instance, when spatial sequence complexity was defined by sequence characteristics, participants were shown to achieve higher estimates of spatial span and greater accuracy at spatial sequencing with structured sequences (De Lillo 2004; Kemps 2001; Parmentier et al. 2005). Even though all these recent studies have shown effects of spatial complexity on memory span or spatial sequencing, none of them had directly addressed the following two questions. One, does sequence complexity and sequence length influence the resolution with which location information is represented; two, do such factors have any impact on how accurately people maintain and rehearse spatial configuration information?

In order to manipulate spatial sequence complexity, in this second study, we varied the number of pathcrossings in the sequences, with more complex sequences having more path-crossings. To do this, we generated Attneave figures, and presented the vertices of these figures as target locations in various orders to yield sequences with one, three, or no path-crossings. This approach ensured that target locations were identical across trials but sequence properties were not. We used the same two dependent measures, distance error and angular error as in the previous study. In addition, using post hoc criteria, we categorized distance errors as indicating representations with high or low resolution. We replicated the sequence length effect from the previous study and also found that as sequence length increased, the resolution of representations decreased, suggesting that people encode longer sequences more coarsely. Also, we demonstrated that for sequences of equal lengths, sequence complexity did not influence the resolution with which each target was recalled. However, for those same sequences, sequence complexity was shown to negatively influence how well the configuration information was preserved. Specifically, the comparison of participants' angular error with angular error from simulated data representing angular error only if absolute positional information were represented, yielded significant differences between sequences with no path crossings, one and three path crossings. While for simple sequences configuration information was maintained above and beyond absolute positional information, for complex sequences it was not (Boduroglu and Shah 2005).

These two studies highlight the configural nature of spatial representations. The fact that spatial configuration information is present in representations fits well with earlier claims that spatial configuration information is effortlessly encoded as people view visual displays (e.g. Simons 1996). Also, it is consistent with conclusions drawn from studies of object tracking arguing that people encode relationships between to-be-tracked targets and direct attention on an unstable yet perceptually grouped configuration (Yantis 1992).

Together, the findings from these studies also point to certain similarities between visual and spatial representations. We argue that spatial representations are configural only for sequences made up of 3 or 4 locations. However, we qualify this observation by demonstrating that spatial sequence complexity also plays a role in the nature of spatial representations; simple but longer sequences may also be represented configurally. A similar influence of complexity of the to-be-recalled items on the nature of visual object representations have has been reported. Contrary to earlier reports arguing that people can maintain visual features of approximately four objects in bound representations in working memory (e.g. Luck and Vogel 1997), more recently it was demonstrated that the actual amount of information that can be maintained in visual working memory is influenced by factors like perceptual complexity and novelty of visual objects (Alvarez and Cavanagh 2004; Eng et al. 2005). These similarities may be reflecting some underlying constraints in the working memory system, probably involving the central control mechanisms (e.g. Cowan 2001).

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