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Qualitative differences in memory for vista and environmental spaces are caused by opaque borders, not movement or successive presentation

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ABSTRACT

Two classes of space define our everyday experience within our surrounding environment: vista spaces, such as rooms or streets which can be perceived from one vantage point, and environmental spaces, for example, buildings and towns which are grasped from multiple views acquired during locomotion. However, theories of spatial representations often treat both spaces as equal. The present experiments show that this assumption cannot be upheld. Participants learned exactly the same layout of objects either within a single room or spread across multiple corridors. By utilizing a pointing and a placement task we tested the acquired configurational memory. In Experiment 1 retrieving memory of the object layout acquired in environmental space was affected by the distance of the traveled path and the order in which the objects were learned. In contrast, memory retrieval of objects learned in vista space was not bound to distance and relied on different ordering schemes (e.g., along the layout structure). Furthermore, spatial memory of both spaces differed with respect to the employed reference frame orientation. Environmental space memory was organized along the learning experience rather than layout intrinsic structure. In Experiment 2 participants memorized the object layout presented within the vista space room of Experiment 1 while the learning procedure emulated environmental space learning (movement, successive object presentation). Neither factor rendered similar results as found in environmental space learning. This shows that memory differences between vista and environmental space originated mainly from the spatial compartmentalization which was unique to environmental space learning. Our results suggest that transferring conclusions from findings obtained in vista space to environmental spaces and vice versa should be made with caution.

1. Introduction

The ability to remember the location of non-visible targets is essential for a multitude of everyday life tasks, such as communicating the direction to the train station to a non-local person or pointing to a certain cupboard in the kitchen to guide your cooking mate. In order to solve such problems, target locations have to be represented in memory. People have the ability to remember locations in their immediate visible surrounding, i.e., vista space, such as rooms, corridors or open spaces (Montello, 1993). In vista spaces, properties of the surroundings and configuration of objects in space can be perceived from one vantage point by taking a look around. Yet, people are also capable of combining information from several interconnected vista spaces, i.e., an environmental space, such as in buildings or cities (Montello, 1993). Information, in this case, has to be gathered by traversing through and experiencing multiple spaces. Object-to-object relations have to be established mentally, for example, by integrating them into a single reference frame.

Prior studies have already indicated differences between spatial representations acquired in vista and environmental spaces. Firstly, it was found that borders of visibility often determine mental updating of object locations. Namely, locations beyond the currently visible vista space (e.g., locations on a campus) are less likely to be updated compared to locations within the same vista space (e.g., objects in a room) (Avraamides & Kelly, 2010; Kelly, Avraamides, & Loomis, 2007; Wang & Brockmole, 2003a, 2003b). Such results suggest that the self-to-object updating process concentrates more on the immediate environment and less on distant targets exceeding the current vista space. Secondly, locations within one vista space unit seem to have a greater degree of "mental closeness" than locations separated by spatial borders. Despite having the same Euclidean distance, the distances between objects

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is judged as being shorter within a single unit (e.g., room) compared to across units (e.g., to the next room) (Kosslyn, Pick, & Fariello, 1974; McNamara, 1986; Newcombe & Liben, 1982). Thirdly, switching between distinct environmental representations is costly, which manifests in increased response times (Brockmole & Wang, 2002, 2003; Wang & Brockmole, 2003a, 2003b). Also, memory of environmental spaces can be comprised of multiple, local reference frames, one for each single vista unit of the environmental space (e.g., for each traveled passage of a route) (Meilinger, Riecke, & Bülthoff, 2014; Werner & Schmidt, 1999). In general, these results suggest that entering a new vista space by passing a visual border strongly affects how we represent the space and that an environmental space is potentially represented segmentally, comprising multiple vista space units.

Importantly, most of these experiments did not control for the amount of information that is needed to be processed within a vista or an environmental space. The number of objects that had to be taken into account and the area that needed to be covered mentally was always larger for the environmental space compared to the vista space, for example when retrieving memory of object location within and beyond the current test room, thus increasing memory load for the environmental space compared to the vista space (e.g., Brockmole & Wang, 2002, 2003; Kosslyn et al., 1974; McNamara, 1986; Newcombe & Liben, 1982). Therefore, effects might at least partially be explained by these differences. In order to match information quantity, we examined participants' configurational memory after learning *exactly the same* object layout (keeping distances and angles constant) either within a vista space or in an environmental space.[2] In the following we will derive three hypotheses about potential differences that may arise in the spatial representations of the layout. In a second step, we will examine how distinct learning characteristics within vista and environmental spaces may underlie these differences.

1.1. Order effects

Learning an environmental space is inevitably temporal. One needs to pass through a discrete vista unit to perceive the next one. Thus, objects are encountered successively in a specific order. Several studies have examined the effects of order during spatial tasks. Results by Strickrodt, O'Malley, and Wiener (2015) suggest that when learning a route, people memorize the sequence of encountered landmarks along the way in combination with the corresponding turning direction. Landmark and turning information of the preceding intersection were used to infer the correct direction of turn at the following decision point. Object order is also used to identify overall route direction, i.e., forward direction or return path (Wiener, Kmecova, & de Condappa, 2012). How engrained object order is in spatial memory was demonstrated in a priming experiment by Janzen (2006). After learning a route in a large-scale virtual environment containing a range of landmarks, subsequent recognition was faster when participants were primed with a former predecessor landmark, compared to a former successor landmark (see also Schweizer, Herrmann, Janzen, & Katz, 1998). These results are in line with the assumption that the representation of a route is highly integrated, following a stimulus-response-stimulus pattern that allows memorizing route landmarks as a sequence (e.g., O'Keefe & Nadel, 1978).

These studies all target characteristics of the acquired route knowledge. Interestingly, in addition to the above-mentioned results, route direction was also shown to influence performance in tasks designed to address configurational memory (survey tasks), even though, typically configurational knowledge is thought to be uncoupled from the order of learning. In a study by Moar and Carleton (1982), participants were more accurate in directional and distance judgements to targets along a route when probed in the direction they had previously learned the route than in the opposite direction. For example, performance was better while standing at the location of the first object along the route and pointing to the third object encountered during learning than pointing from the third object to the first object. These results suggest that route direction is preserved within configurational memory and used not only for route tasks, but also for survey tasks. This result only represents an indirect examination of whether object order is incorporated in participants' configurational knowledge when learning takes place in an environmental space. In the current study, however, we aimed for a direct measure by letting participants perform a configurational placement task, where the layout of environmental objects had to be reproduced from memory. We predict that, when learned in environmental space, the reconstruction of objects follows the order in which they were first encountered. This order should be easiest to retrieve and, as a result, most preferred. In contrast, presentation of an object layout in a vista space does not impose a predetermined learning order. All objects are visible at once. Access of configurational memory could be flexible following random order. Alternatively, scanning patterns during learning might influence retrieval. These scanning paths might be random as well, thus, being unique for every participant. There is also evidence for systematic scanning paths of grid layouts along horizontal paths (Gilchrist & Harvey, 2006; Hardiess, Gillner, & Mallot, 2008). In sum, whereas environmental space learning should predetermine one specific order, the order of retrieving configurational memory from vista space should be much more varied.

1.2. Distance effects

Following the abovementioned results (Avraamides & Kelly, 2010; Brockmole & Wang, 2002, 2003; Kelly et al., 2007; Kosslyn et al., 1974; McNamara, 1986; Meilinger et al., 2014; Newcombe & Liben, 1982; Wang & Brockmole, 2003a, 2003b; Werner & Schmidt, 1999), a compartmentalized space might cause the mental representation to be compartmentalized as well. Learning an environmental space is highly restricted compared to vista space learning. Vision of the entire space is obstructed, the order connected vista spaces are successively entered is predefined as well as the walking distance between locations along the route. We assume that retrieving spatial information will depend on this predefined structure of space.

There is evidence suggesting that distance information from the learning experience might still be preserved within configurational memory. Thorndyke and Hayes-Roth (1982) reported an increased error in directional and distance judgements dependent on the number of corridors between the participant's current position and target location. One possible explanation for this increasing error with distance could indeed be that during task execution (retrieval process), memory of the environmental space is retrieved successively, along the route from which the environment was experienced from. This might be realized, for example, by mentally walking down the memorized route starting from the current location and approaching the target (Byrne, Becker, & Burgess, 2007; Sanders, Rennó-Costa, Idiart, & Lisman, 2015) or by constructing a mental model of the non-visible parts of the environment corridor-by-corridor from one's

[2] Studies utilizing vista space learning usually test what they call *object-to-object relations* (e.g., Avraamides & Kelly, 2010; Mou & McNamara, 2002; Yamamoto & Shelton, 2009). Studies exploring navigation and wayfinding in environmental space typically examine object-to-object relations as well, but subsume it under the term *survey knowledge* (i.e., knowing where a target is located in terms of direction and distance without necessary knowing a route leading there; e.g., Siegel & White, 1975).