

Encoding modality and spatial memory retrieval

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ABSTRACT

This study examined the temporal characteristics of event-related brain electrical activity associated with the processing of spatial memories derived from linguistic and tactile information. Participants learned a map by (1) reading a text description of the map, (2) touching a wooden topological representation of the map (hidden from view), or (3) both. Subsequently, the participants' ability to use their spatial knowledge was tested in a spatial orientation task. Differential patterns of brain activity as a function of encoding modality were found at the very early (preconscious) stages of processing. In contrast, an analysis of behavioral performance revealed no differences between the encoding groups. A model of spatial memory retrieval is presented to account for the findings.

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1. Introduction

People's ability to remember information has been one of the primary areas of psychological research. The present paper focuses on one particular aspect of human memory, namely, our ability to encode spatial information. Spatial memory is a critical skill for both humans (McDonald & Pellegrino, 1993) and animals (Poucet, 1993) alike. Humans acquire spatial knowledge principally by navigating through environments. Exploration of large-scale spaces involves the assimilation of multiple views over time (Kuipers, 1982) resulting in an overall mental representation of the environment.

Spatial information can be conveyed through several modalities. For example, people can acquire spatial knowledge on the basis of verbal instructions. Wilson, Tlauka, and Wildbur (1999) asked participants to learn simple routes, which were presented as written descriptions. The routes were described from either a map perspective, or from the perspective of someone taking an actual journey along the path. Participants' spatial knowledge was assessed by asking them to imagine themselves in specified orientations at points along the path, and to make judgments about the direction to several target localities. Wilson et al. found that after reading a description of a simple environment participants were able to make spatial judgments based on the verbal descriptions. Ungar, Blades, and Spencer (1997) examined the encoding of spatial information based on the haptic modality. The researchers observed that tactile maps (also known as Braille maps) facilitated distance judgments in blind children. The present paper investigates whether spatial memories encoded in one type of modality

differ from those derived from another sensory modality, a question that has its roots in the debate about whether mental representations are pictorial/perceptual or symbolic/abstract in nature (see Kosslyn, Ganis, & Thompson, 2003; Pylyshyn, 2003).

An examination of modality specificity provides an interesting insight into the relationship between encoding and retrieval processes. If spatial information were retrieved from a dedicated spatial system (Bryant, 1992) that stores spatial information in a modality-independent manner (spatial memories are indistinguishable irrespective of whether information is acquired, say, verbally or haptically), spatial memory retrieval would be unrelated to the encoding experience. On the other hand, if verbally encoded information were retrieved in a format different from haptic information, this pattern of results would suggest a direct link between encoding and retrieval. Fig. 1 presents a modality-specific model of spatial memory retrieval. According to the model the type of encoding input influences retrieval through the activation of associated input-specific memories. The present study examines one implication of the model – whether the activation of modality-specific memories is part of spatial memory retrieval.

Behavioral studies have demonstrated some similarities between visuospatially and verbally acquired spatial memories. Denis and Cocude (1989) observed that it takes more time to mentally scan longer versus shorter paths when learning is based on text. Similar results have been obtained in studies of visuospatially based materials (Kosslyn, Ball, & Reiser, 1978). Visuospatial tracking has been shown to interfere with the processing of verbal material (Oakhill & Johnson-Laird, 1984). Interference between a visuospatial and verbal task is consistent with a common format for encoding, for if the tasks were processed independently no interference would be expected. More recent work has revealed

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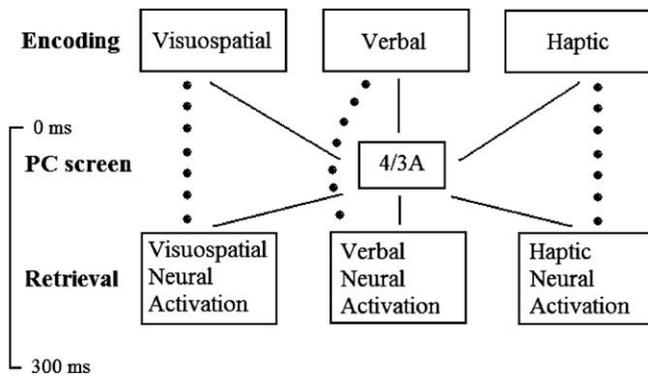


Fig. 1. A model of spatial memory retrieval. Spatial knowledge can be acquired through a number of modalities (the modalities considered here are visuospatial, verbal, and haptic). The solid lines represent the sequence of experimental events: encoding followed by the spatial memory test (PC screen) and retrieval. Timing started on presentation of the test message (0 ms) on the PC screen. Neural activity was analyzed for 300 ms following stimulus onset. The finding that brain activity was modality-specific suggests that retrieval was influenced by associated input-specific memories (represented by the dotted lines).

both similarities and differences in mental representations formed from language and visuospatial input (Avraamides, Loomis, Klatzky, & Golledge, 2004; Klatzky, Lippa, Loomis, & Golledge, 2003).

Electrophysiological studies suggest that spatial memory is modality-specific (see Mazoyer, Tzourio-Mazoyer, Mazard, Denis, & Mellet, 2002, for a summary). Using position emission tomography (PET), Mellet et al. (2002) found that mental scanning based on visual perception and verbal descriptions involved similar neural substrates (e.g., an activation of parieto-frontal networks was observed for both modalities) as well as distinct areas of activation. The right medial temporal lobe was involved following visually-based learning, while verbal learning resulted in an activation of the language areas (see also Mellet et al., 2000).

In a precursor to the present study, Tlauka, Keage, and Clark (2005) employed both behavioral and psychophysiological measurements to examine modality-specificity in spatial memory. In that study, university students were presented with a simple map, or they read an equivalent verbal description of the map. Following learning, the students' knowledge of the map/description was tested in a computer-based spatial task, in which the memorized representation was to be visualised from different orientations, either in the orientation in which it was learned (aligned orientation) or in an orientation that was misaligned (by 180°) from the study orientation (misaligned orientation). Participants were asked to press a specified button as soon as they had a mental image of the orientation. While performing the task, electroencephalographic activity (EEG) was recorded. By averaging EEG time-locked to the onset of specific task stimuli, measures of brain activity were derived that reflected the processing of the orientation stimuli (i.e., event-related potentials or ERPs) with millisecond (ms) resolution.

The electrophysiological analyses focused on the early ERP components (P1, N1, and P2) that are obtained within 300 ms post-stimulus over occipital, temporal, parietal and frontal regions. The pattern of component activity recorded while participants performed the orientation task was found to be affected by the modality in which the map was learned: for example, P1 latency was faster at occipito-temporal electrodes in the verbal learning group while N1 amplitude was stronger at the right occipito-temporal electrode in the visuospatial learning group (but see Allan, Robb, & Rugg, 2000, who did not observe stronger activation at right occipito-temporal sites). The results are particularly remarkable as early ERP components are associated with the *preconscious*

stages of processing that are involved in the analysis of the physical characteristics of stimuli to be attended (Hillyard, Teder-Salejarvi, & Munte, 1998). A noteworthy additional finding was that there were no differences between the verbal and visuospatial encoding groups in the behavioral measures, which reflected the participants' ability to perform the spatial task.

Significant differences in the early components of brain event-related electrical activity as a function of encoding modality are consistent with the assumption that the retrieval of spatial memories is influenced by the modality of the input. It is important to note, though, that in common with related investigations (e.g., Avraamides et al., 2004; Denis & Cocude, 1989; Mellet et al., 2002), Tlauka et al. (2005) compared a visuospatial with a verbal encoding modality. Accordingly, we cannot be certain as to whether modality specificity applies to other modalities, too. The present study was designed to extend our earlier results by investigating haptic input. Participants were presented with a verbal description of a simple map, or they haptically explored a corresponding map (see Fig. 2). Investigations into haptic exploration by visually-impaired (e.g., Hollins & Kelly, 1988) and sighted (e.g., Klatzky, 1999; Klatzky et al., 2003) persons have indicated that spatial knowledge can be acquired relying on the haptic sensory modality only.

We also included a combined stimulus presentation group in which participants touched the map while simultaneously reading a description of it (in the absence of a visual representation of the map). Analysis of the ERP patterns associated with the combined group were intended to inform us as to whether multi-modal encoding leads to a unique pattern of neural activation, or, alternatively, to a pattern more akin to one of the original input modalities.

To summarize, the question of modality specificity in spatial memory is an important one providing clues as to the relationship between encoding and retrieval. Our earlier finding (Tlauka et al., 2005) of differential neural activation as a result of encoding modality was remarkable given that the effects occurred within 300 ms post-stimulus, i.e., at a preconscious level of processing. Prior to presenting a theoretical framework for these results, we considered it necessary to test the validity of the conclusions from the initial findings. The current study examined the temporal characteristics of event-related brain electrical activity associated with the processing of spatial memories derived from linguistic and haptic information. In the recall phase of this study, participants in all three groups imagined the maps/descriptions from an aligned (north-facing) and misaligned (south-facing) orientation. Prior re-

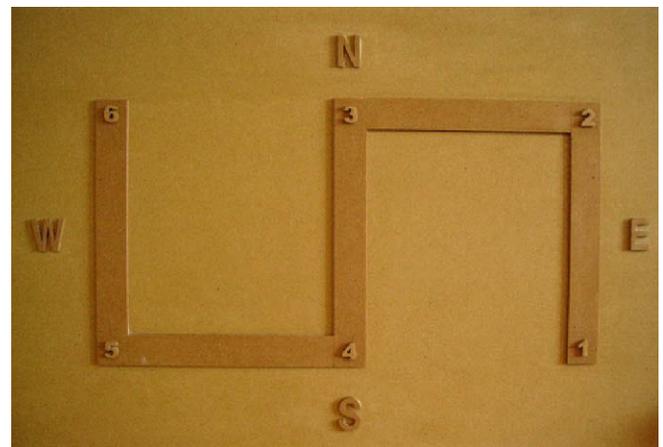


Fig. 2. One of the maps presented to participants in the haptic and combined encoding groups.

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