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What working memory subcomponents are needed in the acquisition of survey knowledge? Evidence from direction estimation and shortcut tasks

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ABSTRACT

This study investigated whether and to what extent verbal and spatial working memory (WM) are implicated in the acquisition of survey knowledge through navigation in a real environment. We adopted a dual-task paradigm, asking participants to learn the layout of two floors of an unfamiliar building by navigation, and to perform either a verbal or a spatial concurrent task. Ninety undergraduates were assigned to one of three groups according to concurrent task condition: articulatory suppression, spatial tapping, or control (no concurrent task). Acquisition of a survey representation was tested by asking participants to perform direction estimations and shortcut tasks. The results showed that the spatial secondary task interfered most strongly with encoding survey knowledge.

1. Introduction

Finding a specific examination room in hospital, the gate in an airport or an office in university are complex cognitive tasks. To successfully reach a destination efficiently, one needs to have a cognitive map, which is an internal spatial representation of an environment (Downs & Stea, 1973) in order to plan and execute a direct route to the desired location.

It is possible to acquire different types of spatial knowledge; knowledge about the identities and position of specific landmarks, route knowledge about specific paths that connect sequences of landmarks, and more flexible spatial representations of the configuration of the environment, referred to as survey knowledge (Siegel & White, 1975). The acquisition of spatial knowledge involves complex cognitive processes because it requires information sensed during movement in the environment to be filtered, integrated, and then stored in memory (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006).

This study focused on the cognitive processes involved in the acquisition of survey knowledge. Survey knowledge is flexible knowledge of the layout of an environment that represents the distances and directions between landmarks independently of the routes between them, and allows for planning direct paths to unseen goal locations. When constructing survey representations, it is assumed that landmarks and routes are encoded and integrated with each other to construct a representation of a global configuration, often maintaining an extrinsic point of view.

As shown in one model of learning spatial layout from navigation experience (Hegarty et al., 2006), working memory has a key role in the construction of internal spatial representations. As a person moves through an environment, he or she encodes spatial information sequentially from various sources of sensory information. Working memory is required to maintain this sequentially encoded information, in order to integrate and store it in memory, and to infer new information, such as the global configuration of the environment, which is not viewed directly when moving through an environment (Hegarty et al., 2006).

According to Baddeley's model, working memory is not a unitary system, but it is possible to distinguish an attentional control system—the central executive—and at least two subsystems—the phonological loop and the visuospatial sketchpad, which encodes and maintains verbal information and visuospatial information, respectively (Baddeley & Hitch, 1974). Environmental information is likely encoded in visuospatial working memory (VSWM), but it might be encoded in verbal working memory (VWM), as a sequence of route directions (such as "at the bar turn left, then right, then go ahead") (Allen, Kirasic, Dobson, Long, & Beck, 1996).

A classic method of studying the role of subcomponents of working memory in a cognitive task is the dual task paradigm, in which participants perform a secondary task, which can be spatial

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or verbal, simultaneously with a primary task of interest, and performance in these "dual task" conditions is compared to a control condition in which participants just perform the primary task. Impaired performance in a dual task condition, relative to the control condition, supports the notion that the same subcomponent of working memory is involved in the primary and secondary tasks (Lindberg & Gärling, 1981).

Recent studies using the dual task paradigm to explore the acquisition of spatial knowledge suggest that, in the case of landmark and route knowledge, the information is encoded in both the spatial and verbal subcomponents of working memory (Garden, Cornoldi, & Logie, 2002; Meilinger, Knauff, & Bulthoff, 2008; Wen, Ishikawa, & Sato, 2011, 2013). Researchers have also begun to investigate the relationship between working memory and acquisition of survey knowledge (Coluccia, 2008; Coluccia, Bosco, & Brandimonte, 2007; Wen et al., 2011, 2013).

Coluccia and colleagues studied the acquisition of survey information from maps. In one experiment (Coluccia, Bosco, et al., 2007; Coluccia, Iosue, & Brandimonte, 2007), participants studied the map of a real place (the Palatino, an archeological site in Rome) while performing either a verbal or spatial secondary task, or with no interference (control group). As a measure of survey knowledge, they recorded the number of landmarks properly placed on a drawn map. Results revealed that the spatial (but not the verbal) secondary task impaired performance, suggesting a selective involvement of VSWM in acquisition of survey knowledge from a map.

Survey knowledge can also be acquired from navigation. However there are individual differences in ability to successfully complete survey tasks after navigation experience alone (without seeing a map). Gender could also be an important factor in the acquisition of spatial knowledge. However while some studies of map learning (e.g., Coluccia, Iosue, et al., 2007) reported that males were more accurate than females, in the acquisition of spatial knowledge from real environment the differences of the gender are less consistent (see Coluccia & Louse, 2004 for a review). In addition, people who report that they have a good sense of direction are better able to complete survey tasks (such as pointing to unseen locations) after navigating in a building than those who report a poor sense of direction (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002; Ishikawa & Montello, 2006). When people are asked about their navigation strategies, those who report constructing survey representations (and not just landmark or route representations) also perform better at survey tasks (Pazzaglia, Cornoldi, & De Beni, 2000; Pazzaglia & De Beni, 2001).

Recently, a study of learning from navigation (Wen et al., 2011) documented that individual differences in sense of direction interact with subcomponents of working memory in selectively affecting the acquisition of survey knowledge. Wen et al. (2011) asked participants to learn routes from videos while performing verbal, visual, and spatial secondary tasks or with no secondary task (control condition). They concluded that participants with a good sense of direction integrated knowledge about landmarks and routes to construct survey representations with the support of all three components of working memory. In contrast, participants with a poor sense of direction failed to encode and integrate landmarks spatially to construct accurate survey knowledge.

Questions remain about how different components of working memory are involved in the acquisition of survey knowledge in learning spatial layout in a real environment. Previous studies have examined the acquisition of survey knowledge from maps (Coluccia, Bosco, et al., 2007; Coluccia, Iosue, et al., 2007) and from videos (Wen et al., 2011). It should be noted that a map is a survey representation in which all spatial information is simultaneously visible, so that constructing a survey representation merely involves memorizing the map. In contrast, in learning from real navigation one learns the layout sequentially as one moves through the environment, one's orientation changes constantly and the amount of spatial information visible at any time is limited (Taylor, Naylor, & Chechile, 1999; Thorndyke & Hayes-Roth, 1982). Learning from a video also involves viewing spatial information sequentially from inside the environment, but it differs from learning from real navigation in that proprioceptive and vestibular information from self-motion are not available. These body-based senses have been shown to contribute to spatial updating (e.g. Klatzky, Loomis, Beall, Chance, & Golledge, 1998) and previous research has shown a dissociation between ability to learn from a video and from navigation in a real environment (Hegarty et al., 2006).

In previous research survey knowledge has been measured using performance on map drawing tasks and pointing to unseen landmarks. Both of these tasks can be completed on the basis of survey knowledge (Richardson, Montello, & Hegarty, 1999), although an accurate map can also be completed on the basis of route knowledge (Hegarty et al., 2006). In addition, finding a shortcut, is a task used classically to measure whether an animal has constructed a *cognitive map* of the environment (Tolman & Honzik, 1930, pp. 215–232; see also Gallistel, 1990; Tolman, 1948). Indeed, to find the shortest route to reach a goal, the use of both a body-centered system (to navigate in the environment) and a configurational representation (to individuate the shortest route) are necessary (Golledge, 1999).

Our study used the dual task paradigm to examine the influence of subcomponents of working memory in the construction of a survey representation during navigation by walking in a real environment. In contrast with previous research examining the role of working memory in outdoor navigation (Garden et al., 2002; Meilinger et al., 2008; Wen et al., 2011, 2013), we studied navigation in an indoor environment, which included the added complexity of integrating the locations of landmarks over two floors of the same building (cf. Montello & Pick, 1993; Richardson et al., 1999). To investigate how one acquires survey knowledge, we used classic measures of finding shortcuts, pointing to unseen landmarks, and map completion.

If the acquisition of survey knowledge requires people to integrate separate landmarks and routes into a configural spatial representation (Ishikawa & Montello, 2006), VSWM, which is specialized for storing spatial information as a configuration (Hegarty et al., 2006), should play a great role in the construction of a survey representation. As a consequence, it should be more difficult for the spatial dual-task group to find shortcuts in the building, to make direction judgments, and to draw an accurate map, compared to the control group. However, it is also possible that spatial knowledge might be acquired and maintained through verbal encoding of spatial information, such as the names of landmarks, sequence of actions, etc. Therefore, both subcomponents of working memory might be involved in the acquisition of spatial knowledge.

A secondary goal of this study was to examine the role of individual differences in sense of direction (Hegarty et al., 2002) and navigation strategy, specifically the strategy used to encode spatial information about the environment (Garden et al., 2002; Pazzaglia & De Beni, 2001; Wen et al., 2011, 2013) through the administration of two self-report questionnaires. According to the literature, people with a preference for using a survey strategy to encode the environment and with a better sense of direction should be more competent in "survey tasks" that require configural understanding of environments (Blajenkova, Motes, & Kozhevnikov, 2005; Hegarty et al., 2002; Kozlowski & Bryant, 1977; Montello & Pick, 1993; Sholl, 1988; Sholl, Acacio, Makar, & Leon, 2000).