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The role of visuo-spatial abilities in recall of spatial descriptions: A mediation model

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ABSTRACT

This research investigates how visuo-spatial abilities (such as mental rotation — MR — and visuo-spatial working memory — VSWM —) work together to influence the recall of environmental descriptions. We tested a mediation model in which VSWM was assumed to mediate the relationship between MR and spatial text recall. First, 120 participants were assessed for MR and working memory (both visuo-spatial and verbal) abilities. Participants then listened to spatial descriptions and performed spatial recall tasks. The expected model was verified, indicating that it is possible to define an order for how visuo-spatial abilities modulate environmental learning, with MR as a predictor and VSWM as a mediator.

One way of acquiring environmental knowledge is through verbal input, such as a spatial description. From this, the listener/reader forms a mental representation, a so-called spatial mental model (Johnson-Laird, 1983); this representation maintains the spatial properties of the text processed, such as relationships between objects (e.g., Taylor & Tversky, 1992). The construction of efficient spatial mental representations depends on several cognitive factors. In this study, we examine the role of visuo-spatial abilities – particularly mental rotation (MR) and visuo-spatial working memory (VSWM) – in building mental representations derived from spatial (environmental) descriptions.

Visuo-spatial abilities allow us to generate, retain, and transform abstract visual images (Lohman, 1979) and are generally distinguished into three sub-factors: spatial perception, spatial visualization, and mental rotation (for an example, see the meta-analysis of Linn & Petersen, 1985). The latter two sub-factors, consisting of the ability to perform multi-step manipulations of complex spatial information (spatial visualization) and to manipulate figures rotating 2D or 3D stimuli (mental rotation), are relevant for environmental learning. For example, Hegarty, Montello, Richardson, Ishikawa, and Lovelace (2006) used a structural equation model to show that visuo-spatial abilities (tested with spatial visualization, mental rotation, and spatial working memory tasks) and sense of direction can predict environmental learning (see also Allen, Kirasic, Dobson, Long, & Beck, 1996). In the current study, the analysis focuses on mental rotation ability, which is shown to be relevant in predicting environmental learning either alone (e.g., Fields & Shelton, 2006; Pazzaglia & De Beni, 2006) or together with other visuo-spatial abilities (e.g., Hegarty et al., 2006). In addition, this spatial ability is involved in the construction of mental representation derived from environmental descriptions (e.g., Haenggi, Kintsch, & Gernsbacher, 1995; Meneghetti, Pazzaglia, & De Beni, 2011; Pazzaglia, 2008). The latter studies typically employed an individual differences paradigm in which groups with different levels of spatial ability were compared. For example, Pazzaglia (2008) showed that high-MR individuals (tested using the Mental Rotations Test; Vandenberg & Kuse, 1978) recalled environmental descriptions presented in survey perspective (better than low-MR individuals using allocentric point of view and extrinsic frame of reference, such as compass directions), although the difference fell when the text was presented together with a map of the same environment.

Another visuo-spatial skill involved when people learn about an environment is the VSWM (as suggested by Hegarty et al., 2006). According to Baddeley's (1986) working memory (WM) model, VSWM is a system devoted to maintaining and processing visuo-spatial information; together with verbal working memory (VWM, which maintains and processes verbal information), these two subsystems are modality-specific controlled by the central executive (CE). Clear evidence of VSWM's involvement in spatial text processing was obtained in earlier studies using an individual differences paradigm. For example, Pazzaglia and Cornoldi (1999, Exp. 1) found that individuals with high spatial span had better spatial text recall than did their lower-ability counterparts. The spatial span was evaluated using the Corsi Blocks task (Corsi, 1972), which is typically used to assess VSWM (e.g., Logie, 1995). The task consists of a series of blocks arranged irregularly on a board and participants must reproduce the sequences of increasing length tapped by the examiner, both in forward and in backward presentation order.

More recent studies have examined the involvement of WM systems in spatial text processing using a dual task paradigm. This procedure consists of performing a primary task (e.g., listening to a spatial

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text) concurrently with a secondary task (e.g., spatial tapping — ST— task, requiring participants to sequentially tap keys located on the board's corners). If the secondary task competes for the same limited WM resources, performance on the primary task is poorer than it is for a single-task condition (e.g., Baddeley & Andrade, 2000; Logie, 1995). It is worth noting that Vandierendonck, Kemps, Fastame, and Szmalec (2004) in a dual task paradigm study found that the Corsi Blocks task requires the involvement of both VSWM and CE (using ST and random-interval generation as secondary tasks).

In a series of studies, recall of environmental descriptions was consistently found to be impaired by spatial (using ST) and verbal concurrent tasks, while recall of non-spatial text was impaired only by a verbal concurrent task (e.g., De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Meneghetti, De Beni, Gyselinck & Pazzaglia, 2011; Pazzaglia, De Beni, & Meneghetti, 2007). In the latter studies, spatial descriptions were presented in route perspective, i.e., using an egocentric point of view and intrinsic frame of reference (e.g., "to your left", "behind you", etc.). The use of ST specifically stresses spatial WM resources that are involved in route text processing; thus, the sequential arm movement is supposed to interfere with the character's imagined movement along that path. Some studies showed that in route text (compared with survey text) there is a stronger involvement of VSWM (using ST as a secondary task) (Brunyé & Taylor, 2008; Pazzaglia, Meneghetti, De Beni, & Gyselinck, 2010), of CE (Brunyé & Taylor, 2008) and of spatial–sequential WM (Pazzaglia et al., 2010). These studies further suggest that the building of spatial mental representation derived from route perspective requires the involvement of both visuo-spatial WM and CE processes.

There is evidence that these visuo-spatial abilities (i.e., VSWM and MR) are related to each other. In an initial mediation model study, Miyake, Friedman, Rettinger, Shah, and Hegarty (2001) showed that VSWM tasks (including the Corsi Blocks task) were related to CE tasks, and that visuo-spatial abilities (including mental rotation tasks) required a strong involvement of CE. This indicates that VSWM is involved in storing and processing of visuo-spatial stimulus and that in some cases, such as in mental rotations tasks, additional involvement of CE is required. The forward and backward versions of the Corsi Blocks task are a good example of how VSWM and CE interact. Indeed, while the forward version – consisting of reproducing the sequence of blocks in the same presentation order – is strictly a measure of the VSWM storing component, the backward version – reproducing the blocks in the opposite order of initial presentation – measures both VSWM storing and processing functions. Some studies show that both versions measure spatial WM process (Mammarella & Cornoldi, 2005) but the backward version also requires the involvement of additional CE processes (Cornoldi & Vecchi, 2003, Vandierendonck et al., 2004).

To better understand the relationship between VSWM (using the Corsi Blocks task) and spatial ability (i.e., MR), Cornoldi and Mammarella (2008) investigated differences in the performance of the forward and backward versions of the Corsi Blocks task in individuals with high- and low-MR abilities. Results showed that two groups differed (high better than low) in the backward version but not in the forward version. This corroborates the idea that mentally rotating spatial stimuli requires a spatial-active WM process, which involves CE processes.

To date, there has been no thorough study of how these two visuo-spatial abilities (MR and VSWM) work together to process spatial descriptions. Initial evidence comes from some of our own studies (Gyselinck, Meneghetti, Pazzaglia, & De Beni, 2009; Meneghetti, Gyselinck, Pazzaglia, & De Beni, 2009) where we investigated the role played by spatial ability (selecting individuals with high- and low-MR ability) in relation to VSWM in environmental descriptions processing (i.e., listening to spatial descriptions and concurrently performing spatial or verbal tasks). Gyselinck et al. (2009) found that high-MR individuals maintained good spatial text recall during the performance of spatial and verbal secondary tasks, similar to control condition; their lower-ability counterparts, on the other hand, were affected by both concurrent tasks. Meneghetti et al. (2009) confirmed these results, although additionally high-MR individuals were found to be impaired in ST performance. Overall, these results showed that the two spatial groups involve VSWM during environmental description learning, but to different extents. It is worth noting that these latter studies used a combination of traditional individual differences and dual task paradigms. However, in the present study, we tested the relationships between these variables at a continuous level with mediation models in order to add evidence of how MR and VSWM abilities work together to process environmental descriptions.

We assumed VSWM to be involved in both MR (as suggested, for example, by Cornoldi & Mammarella, 2008) and spatial-route text processing (as suggested, for example, by De Beni et al., 2005). Only route perspective descriptions were considered, as previous studies showed strong VSWM involvement here (Brunyé & Taylor, 2008; Pazzaglia et al., 2010); VSWM could assume the role of mediator between MR and spatial text recall. The MRT, Corsi Blocks and Digit Span (Wechsler, 1981) tasks were administered to a large sample. The Digit Span was used to check the influence of VWM in spatial text recall, given that involvement of this component has already been demonstrated (e.g., De Beni et al., 2005). The same group listened twice to a spatial-route description, then performed free recall and graphical representation tasks. We then proposed a model testing the relationship between MR ability and spatial recall via VSWM mediation.

1. Method

1.1. Participants

A total of 120 (26 males and 94 females) undergraduates from the faculty of Psychology of the University of Padua voluntarily participated (mean age: 23.40 years).

1.2. Materials

1.2.1. Mental rotations test (MRT, Vandenberg & Kuse, 1978)

This test is comprised of 20 items, each presenting one 3D target figure and four possible matches (assembled cubes). The task is to find the two figures identical to the target but rotated in space (time limit: 8 min).

1.2.2. Working memory measures

The Corsi Blocks task (Corsi, 1972) consists of tapping sequences of blocks arranged irregularly on a board. The Digit Span task (Wechsler, 1981) consists of saying sequences of digits. Participants must reproduce the sequences of blocks/numbers in increasing length, in forward or backward order. In both measures, the sequence length varied from 2 to 9 blocks/digits (two sequences were used for each length).

1.2.3. Spatial descriptions

Two spatial descriptions – "Tourist Center" and "Holiday Farm" – that showed to be recalled as well (Meneghetti et al., 2009) were used. In both descriptions, which were similar in length and included 14 landmarks, a person imagines walking along a route. As they move, the landmark locations are gradually defined, using egocentric terms (e.g., "left", "right"). The environments used in both descriptions are regular (a rectangle in "Holiday Farm" and a circle in "Tourist Center"; an initial sentence provides information on the global structure of the environment) and most of the landmarks are disposed on the boundary and in the center. The path begins and finishes at the same point (e.g., Entrance). An extract from the "Holiday Farm" is: "Imagine yourself standing in front the tall boundary walls of a holiday farm stretching over a rectangular area…You start to walk