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The role of visual and spatial working memory in forming mental models derived from survey and route descriptions

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The role of visual and spatial working memory in forming mental models derived from survey and route descriptions

Abstract

This study examines the involvement of spatial and visual working memory (WM) in the construction of flexible spatial models derived from survey and route descriptions. Sixty young adults listened to environment descriptions, 30 from a survey perspective and the other 30 from a route perspective, while they performed spatial (Spatial Tapping [ST]) and visual (Dynamic Visual Noise [DVN]) secondary tasks - believed to overload the spatial and visual working memory (WM) components, respectively - or no secondary task (Control, C). Their mental representations of the environment were tested by free recall and a verification test with both route and survey statements. Results showed that, for both recall tasks, accuracy was worse in the ST than in the C or DVN conditions. In the verification test, the effect of both ST and DVN was a decreasing accuracy for sentences testing spatial relations from the opposite perspective to the one learnt than if the perspective was the same; only ST had a stronger interference effect than the C condition for sentences from the opposite perspective from the one learnt. Overall, these findings indicate that both visual and spatial WM, and especially the latter, are involved in the construction of perspective-flexible spatial models.

Key words: survey descriptions; route descriptions; spatial working memory; visual working memory; dual task paradigm; strategy.

The role of visual and spatial working memory in forming mental models derived from survey and route descriptions

Introduction

Knowledge of spatial relations can be acquired directly (from sensorimotor experience) or indirectly using maps or virtual displays (e.g. Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Montello, Waller, Hegarty, & Richardson, 2004, for a review), or spatial descriptions (Gyselinck & Meneghetti, 2011, for a review). This last modality is a common activity that involves reading or hearing verbal descriptions of an environment, such as an explanation of how to reach a new destination or visit a city. A typical way to convey spatial information verbally is to use descriptions from a route or survey perspective (Taylor & Tversky, 1992): route descriptions present a space, its landmarks and their spatial relations, from an egocentric perspective (or path view) and use an intrinsic frame of reference (e.g. “to your left”, “behind you”); survey descriptions present the space from an allocentric perspective (or bird's-eye view) and use an extrinsic frame of reference such as compass directions (north, south, east, west). The processing of survey and route descriptions leads to the formation of a spatial mental model, i.e. an abstraction that resembles the structure of the corresponding state of affairs in the outside world (Johnson-Laird, 1983), where spatial relations between objects are represented and can be inferred from different perspectives (Perrig & Kintsch, 1985; Taylor & Tversky, 1992). That spatial models can incorporate multiple views was demonstrated by the finding that, after learning descriptions presented from either a survey or a route perspective, respondents were equally accurate in verifying sentences testing spatial relations from both survey and route perspectives (e.g. Taylor & Tversky, 1992; Brunyé & Taylor, 2008a). Such results suggest that spatial models are perspective-flexible and that people are able to extract and manage spatial information from different perspectives. Other studies have revealed, however, that mental models preferentially incorporate the perspective presented in the learning phase, and a cost is associated with switching perspective. Several studies, indeed, showed that participants were more accurate in judging sentences expressed from the same perspective as the one learned (e.g. Perrig & Kintsch, 1985; Meneghetti, Pazzaglia, & De Beni, 2011; Meneghetti, Borella, Muffato, Pazzaglia & De Beni, 2014). Various factors may be involved in generating difference between results, but little research has been devoted to the issue to date. Among the various factors to consider, cognitive abilities could have a central role in explaining the mechanisms underlying the development of perspective-flexible spatial models. In particular, analysing such cognitive mechanisms as working memory (WM) should shed light on whether the encoding phase is crucial in defining the foundations for building spatial models capable of managing information from different perspectives. It may be that the allocation of WM resources changes as a function of the spatial perspective and could result in a more or less flexible model depending on the availability of resources. The present study examines whether WM supports the development of perspective-flexible spatial models derived from survey and route descriptions.

Survey and route descriptions and working memory

The theoretical model considered here to explore how WM is involved in learning survey and route descriptions was proposed by Baddeley (Baddeley,1986; 2000): WM is seen as a temporary storage and processing system with a central executive (CE) supervising two components, one verbal (VWM) that stores and processes verbal material, and the other visuo-spatial (VSWM). It has been widely accepted that the latter can be divided into visual and spatial functions (e.g. Cornoldi & Vecchi, 2003; Logie, 1995), that store and process visual information (e.g. colour, shape, texture) and spatial information (such as movement and relationships between elements), respectively (Logie & Marchetti, 1991; Salway & Logie, 1995). The dual task paradigm has typically been used to test WM involvement in complex cognitive tasks, such as description learning. It involves completing a primary task (such as hearing or reading a description) while also performing a secondary task designed to load spatial WM, as in spatial tapping [ST], i.e. tapping on four buttons located in the corners of a board, or verbal WM, as in articulatory suppression [AS], i.e. repeating a set of syllables (e.g. Logie & Marchetti, 1991). If the secondary task competes for the same resources as those needed in the primary task, it impairs performance in the primary task.

Using the dual task paradigm several studies have consistently shown that, after hearing or reading spatial descriptions (from a route perspective in most cases) or non-spatial control descriptions – the primary task - while performing ST or AS, only the accurate recall of spatial descriptions was impaired by ST, while AS damaged the recall accuracy of both spatial and non-spatial descriptions (De Beni, Pazzaglia, Gyselinck & Meneghetti, 2005; Gyselinck, De Beni, Pazzaglia, Meneghetti, & Mondoloni, 2007; Meneghetti, De Beni, Gyselinck, & Pazzaglia, 2011; Meneghetti, Gyselinck, Pazzaglia, & De Beni, 2009).

A few studies examined the involvement of WM in learning survey descriptions, comparing this type of description with those presented from a route perspective, and showed that ST and AS damaged recall accuracy for both types of spatial description, with a more pronounced ST interference effect for route descriptions (Brunyé & Taylor, 2008b; Pazzaglia, Meneghetti, De Beni & Gyselinck, 2010). For instance, Pazzaglia et al. (2010) showed that after listening to survey and route descriptions while performing secondary tasks, recall accuracy was damaged by AS and ST for both types of description, and ST had a stronger interference effect on route descriptions than on survey descriptions. They tested recall accuracy using tasks that presented information from the same perspective as in the description learnt, however (or at least not explicitly requiring the use of another perspective), i.e. free recall (participants were asked to report all the information they recalled), and a sentence verification test (on the truthfulness of spatial relations expressed from the same perspective as in the description learnt). So their findings cannot support any clear conclusions on the allocation of WM resources when shifting from one perspective to another.

To our knowledge, only Brunyé and Taylor (2008b), approached the question of WM involvement in processing survey and route descriptions, and its role in supporting inference across perspectives. In their study, participants read survey and route descriptions while performing ST and AS, and their recall was tested with a map drawing task and by means of a verification test that included verbatim, paraphrased and inferential survey and route sentences. Their results showed that, after learning both types of description, AS negatively affected recall accuracy for all types of sentence; in the ST condition recall accuracy was lower than in the control condition for both inferential survey and route sentences (with a stronger effect after learning a route description), and ST also impaired map drawing accuracy for both types of description.

Overall, these results indicate that both verbal and spatial WM support the formation of spatial models derived from survey and route descriptions, and that spatial WM has a specific role when information is presented from a route perspective. Processing information from a survey or route view does not seem to place an additional load on WM resources when it comes to inferring spatial information across perspectives. However, since only Brunyé & Taylor (2008b) have approached this issue so far, the question warrants further investigation.

In addition, only verbal and spatial WM have been considered so far, but another component of WM might be involved in supporting the formation of perspective-flexible spatial models, and that is visual WM. Spatial models may be configured as mental images of the environment (Denis & De Vega, 1993), taking the form of pictures of the path and layout described, for instance. It has been demonstrated that the recall of spatial descriptions is supported by mental images, which may be reported spontaneously (Meneghetti, De Beni et al., 2011), or elicited by instructions (De Beni & Moè, 2003; Gyselinck et al., 2007). Participants report using imagery strategies (“I formed a mental image”) when having to memorize spatial descriptions (Meneghetti, Labate, Ronconi, Grassano & Pazzaglia, 2014). There is also some evidence of visual WM supporting the generation of images referring to verbal material, such as words (Quinn & McConnell, 1996; 2006), and letters (Borst, Niven, & Logie, 2012). As a secondary task for loading visual WM, Quinn and McConnell (1996) proposed Dynamic Visual Noise (DVN), which involves watching a display of dots akin to static on a screen, where the dots randomly change between black and white. In a series of experiments Quinn and McConnell (2006) showed that watching the DVN stimulus while trying to learn lists of words negatively affected accuracy more when the words were processed using visual strategy (pegword mnemonic strategy) than when a rote rehearsal strategy was used. What has yet to be explored is whether visual WM supports the representation of the environments described (which may be founded on mental images), and whether the burden on WM increases when mental pictures are seen from different perspectives. If that is the case, then visual WM may be involved in the formation of perspective-flexible spatial models.

Some studies examined the role of visual WM in environment description learning (Pazzaglia & Cornoldi, 1999; Deyzac, Logie, & Denis, 2006), showing a clear involvement of spatial WM and a limited involvement of visual WM. In a first study, Pazzaglia & Cornoldi (1999) asked participants to learn environment descriptions from route and survey perspectives, or descriptions presenting the visual features of environments while concurrently performing visual and spatial (-sequential and -simultaneous) tasks that involved seeing objects in a layout that could change - in terms of one type of object, one object’s position, or the objects’ order of presentation – with respect to the previously-presented layout, respectively loading visual, spatial-sequential and spatial-simultaneous aspects of WM (Cornoldi & Vecchi, 2003). The results showed that accuracy of survey and route description recall was more impaired by the spatial-sequential task (with a type of WM demand resembling that of the ST task), than by the tasks loading spatial-simultaneous or visual WM. In a further study, Deyzac et al. (2006) asked participants to listen to urban-like environment descriptions from survey or route perspectives while performing spatial (ST), verbal (AS) and visual (DVN) tasks. Their results showed that, for both types of description, ST negatively affected the recall of the positions of landmarks, with a strong interference effect on route descriptions (as previously shown by Brunyé & Taylor, 2008b; Pazzaglia et al., 2010); while interference effects of AS and DVN were limited in a measure testing the recall of landmarks (but not of their positions).

Overall, this literature review shows that few studies have approached the question of how visual and spatial WM allocate resources to handling information across perspectives or, in other words, whether these systems are involved in forming a perspective-flexible representation. On the whole, the literature indicates that: i) spatial WM is involved in learning both survey and route descriptions (Pazzaglia & Cornoldi, 1999), and particularly the latter (Pazzaglia et al., 2010), with no extra burden on spatial WM when extracting spatial relations from different views from the one learnt (Brunyé & Taylor, 2008b); and since only Brunyé and Taylor (2008b) explored the role of WM in supporting the formation of perspective-flexible spatial models, this issue is investigated in the present study; ii) visual WM seems to be only marginally involved, by comparison with spatial WM, in learning survey and route descriptions, though only two studies have explored this matter (Pazzaglia & Cornoldi, 1999; Deyzac et al., 2006). On the basis of these few studies, no clear conclusions can be drawn as to the role of spatial and visual WM in supporting the flexibility of spatial models.

Aims of the study

The aim of the present study was to explore the role of spatial and visual WM in supporting the formation of spatial models derived from survey and route descriptions, analysing whether the allocation of WM resources changes when handling spatial information across perspectives, i.e. when developing perspective-flexible spatial models. One of two groups of participants listened to three descriptions of outdoor environments presented from a route perspective, while the other heard three descriptions presented from a survey perspective. At the same time, they performed spatial (ST) or visual (DVN) tasks, or no secondary task (control condition, C). ST was used as a spatial task because it loads spatial WM resources, competing with both survey and route description processing (Brunyé & Taylor, 2008b). DVN was chosen as a visual task because there is evidence of it interfering with imagery in word processing (Quinn & McConnell, 2006). Some precautions were taken with the latter, however: a) since only 5% of the dots on screen changed per second and limited interference effects were found on spatial descriptions in Deyzac et al. (2006), we increased the task’s impact by making 50% of the dots change (as, for instance, in Dean, Dewhurst, & Whittaker, 2008; and McConnell & Quinn, 2004); b) we counted the eye fixations on different parts of the screen to ensure that participants were watching the DVN stimulus. After hearing each description, participants performed a free recall task (reporting everything they remembered of the landmarks and their spatial relations), and then answered true/false sentences testing spatial relations that were not directly mentioned in the descriptions, from both a survey and a route perspective (similarly to Brunyé & Taylor, 2008b). The two groups' WM abilities were compared by means of visual, spatial and verbal WM tasks.

The role of visual and spatial WM in the development of spatial models derived from survey and route descriptions was tested based on the following assumptions:

a) concerning spatial WM, we expected ST while hearing survey and route descriptions to interfere with spatial information processing, impairing recall accuracy (in both free recall and the verification test) for both types of description by comparison with the C condition (as previously reported in De Beni et al., 2005; and Gyselinck et al., 2007, for instance). The verification test reveals whether the involvement of spatial WM resources changes when spatial relations are tested from the same or a different perspective from the one learnt. There may be a stronger engagement of WM in processing route as opposed to survey descriptions (as Brunyé & Taylor, 2008b, found); we planned, however, to ascertain whether perspective switching requires stronger spatial resources than no perspective switching (i.e. when relationships between landmarks are tested from different or the same views as the one learnt, respectively) after learning both survey and route descriptions.

b) as concerns visual WM, we explored whether DVN interferes with the formation of mental images of a verbally described environment, impairing its recall (in both free recall and the verification test) in the DVN vis-à-vis the C condition (as suggested by Quinn & McConnel, 1996, 2006). If visual WM supports mental image formation (Quinn & McConnell, 2006), then DVN may interfere with image representation during the development of spatial models. We therefore examined whether the involvement of visual WM resources changes when relationships between landmarks have to be visualized from the same or different perspectives from the one learnt.

The effect of WM loading on spatial description learning is also explored in the secondary task. Previous studies had shown a change of ST rhythm from single to dual task conditions, which was interpreted as an interference effect on the secondary task (Gyselinck et al., 2007; Meneghetti et al., 2009), so we examined whether ST rhythm changed from the single to the dual task condition in our study too. In parallel, WM loading by DVN was ascertained from the change in eye fixation counts within an area of interest when switching from the single to the dual task condition.

As a complementary aim, we also explored whether the self-reported strategies used to memorize spatial descriptions - distinguishing between spatial (survey and route) and verbal strategies (Meneghetti, De Beni et al., 2011; Meneghetti, De Beni, Gyselinck, & Pazzaglia, 2013) - changed as a function of the perspective of the description being learnt and of WM involvement. We expected spatial (survey and/or route) strategies use to be rated higher than verbal strategy use (as shown by Meneghetti, De Beni et al., 2011; Meneghetti et al., 2013) for both types of spatial description, with a congruency effect between the type of description heard and the type of strategy used (Meneghetti et al., 2013). We also examined whether strategy usage ratings changed as a function of the load exerted by any spatial and/or visual secondary tasks (as suggested by Meneghetti, De Beni et al., 2011, who found that spatial strategies were used less while hearing route descriptions in association with ST than in a C condition).

Method

Participants

A group of 60 undergraduates (48 females, mean age 20.5 years) took part to the Experiment: 30 participants heard a description from a route perspective, and 30 from a survey perspective (there were 24 females and 6 males in each group).

Material

Descriptions

Six spatial texts (adapted from Meneghetti, Pazzaglia, & De Beni, 2011; Pazzaglia et al., 2010) described three fictitious open environments (a nature park, a tourist centre and a holiday farm) from route and survey perspectives. The descriptions were comparable in difficulty (as previously ascertained by Pazzaglia et al., 2010). They each contained 12 sentences (from 285 to 319 words) and mentioned 14 landmarks. The survey descriptions presented the spatial relations between landmarks using compass points (north, south, east and west), the route descriptions using egocentric terms in the second person (turn left, turn right, go straight on, behind you).

Verification test

Twenty inferential sentences were prepared for each text (adapted from Meneghetti, Pazzaglia, & De Beni, 2011): 10 sentences (half of them true and half false) tested spatial relations not mentioned explicitly in the route descriptions, and 10 concerned the survey descriptions. The sentences were of equal difficulty (as ascertained by means of a pilot study).

Concurrent tasks

Spatial tapping (ST). A rectangular 30 x 24 cm board was used on which four cylindrical keys (3 cm high x 3 cm in diameter) were placed near the four corners of the board, with a gap between them of 24 cm on the longer sides and 18 cm on the shorter sides (as done in previous studies, Meneghetti, De Beni et al., 2011; Meneghetti et al., 2013). The task consisted in tapping the keys sequentially anticlockwise with the index finger. An electrical sensor underneath the board recorded the pressure on each key, and the number of taps was shown on a display alongside. The dependent variable was the number of taps in the total time available.

Dynamic visual noise (DVN). This consists of a grid of 80 × 80 cells, each measuring 2 × 2 pixels (6400 pixel in all). At any one time, 50% of the pixels were white and 50% were black. The pixels randomly changed between black and white at a rate of 50% per second, the only constraint being that the balance of black and white cells had to be preserved (as in Dean et al., 2008). Two movies (.vmw) were prepared, one lasting 360 seconds (like the audio presentation of the environment description), and one 30 seconds for familiarizing participants with the task. The movie advanced at a rate of 15 frames per second, and for each frame 214 cells changed colour. Eye movements were recorded while participants watched the DVN movies using a Tobii T120 eye tracker, manufactured by Tobii Technology (Stockholm, Sweden), integrated in a 17-inch TFT monitor with a maximum resolution of 1280 x 1024 pixels. The camera samples pupil location and pupil size at a rate of 120 Hz. Data were recorded with Tobii-Studio (2.1.14.) software.

As a dependent variable we considered the number of eye fixations (one every 80 milliseconds; see Rayner, 2009, for a review), distinguishing between five regions of interest (ROI) as follows: ROI 1 - horizontal rectangular up, 18% of the screen; ROI 2 - vertical rectangular left, 16% of the screen; ROI 3 - vertical rectangular right, 16% of the screen; ROI 4 - elliptical in the centre, 27% of the screen; ROI 5 - rectangular down, 18% of the screen.

Strategies questionnaire

The questionnaire listed three types of strategy used to memorize spatial descriptions (Meneghetti, De Beni et al., 2011): survey (“I constructed a mental map of the environment”), route (“I mentally followed the path”) and verbal, based on repetition (“I mentally repeated the text). Answers were given using a Likert scale indicating participants’ use of each strategy from 1 (very little) to 5 (very much).

Working memory tasks

The Corsi blocks task (Corsi, 1972) involves tapping sequences of blocks placed at random on a board. The Digit Span task (Wechsler, 1981) involves saying sequences of digits. In both cases, participants are asked to reproduce increasingly long sequences of blocks/numbers in forward or reverse order. In both measures, the length of the sequences varied from 2 to 9 blocks/digits (and two sequences were used for each length). The final score corresponds to the number of items in the longest sequences correctly reproduced.

Just Noticeable Difference (JND, Phillips & Hamilton, 2001). The JND comprises six levels of difficulty, with 20 trials for each level. The stimuli consist of a single square that appears for 2 seconds and, after a 4-second interpolated retention interval, a second square of either the same or a different size is presented in an offset position. Participants are asked whether or not the second square is the same size as the first. The spatial location and size (in pixels) of the stimulus to remember was varied randomly across trials. Up to 20 trials were completed at each level, and the criterion for progression to the next level was 15/20 (binomial probability/.05) to counter the .5 probability of participants guessing. The percentage change in the size of the second square in each pair was reduced from one level to the next, from 50% at the entry level to 6% at the most difficult level. Participants' scores consisted of the most difficult level at which the criterion for progression was satisfied, a lower JND value indicating a better performance.

Procedure

Participants were tested individually in a single session lasting about ninety minutes. After signing to give their informed consent, they were instructed to listen to three spatial descriptions and to perform the recall tasks, and two of the three descriptions were associated with secondary tasks. Participants were randomly assigned to two groups and heard three descriptions from either a survey or a route perspective (route group vs survey group). Each participant listened to one of the three descriptions alone (C), and again while performing a secondary task, which was either ST or DVN (the order was balanced).

The apparatus used to conduct the experiment was the E-prime 2 software (using a laptop) and Tobii T120 (using a desktop PC). The E prime program was used for: the audio presentation of the descriptions and the sentences in the verification test (in previously-created .mp4 files); recording participants' oral free recall and the answers they gave in the verification test (free recall and “true/false” answers were recorded using a microphone and producing .mp4 audio files); recording participants’ keyboard input for the strategy questionnaire (from 1 for “very little” to 5 for “very much”). The Tobii T120 was used to record eye fixation during the DVN movie. Participants were seated in front of the Tobii monitor (approximately 30 cm away), with the laptop beside it. When participants were in the ST or C condition, the Tobii monitor was switched off.

Participants were first familiarized with the concurrent secondary tasks (ST and DVN). For ST, they pressed the keys on the board in counter-clockwise order (at a rate of approximately 1 per second) for 30 seconds. For DVN, first the eye tracker was calibrated using a 9-point procedure, then participants watched the Tobii T120 monitor showing a DVN movie for 30 seconds and eye fixations were recorded.

Participants then listened to spatial descriptions twice (for a total of 360 seconds), first alone and then concomitantly with ST or DVN. In the ST condition, participants performed the ST all the time they were listening to a spatial description; in the DVN condition, eye tracker calibration was repeated and then participants listened to the spatial description while watching the projection of the DVN movie.

After hearing each description, participants reported their free recall and answered the verification test (in a balanced order across participants). In the free recall task, participants said aloud all the information the remembered; in the verification test they heard sentences randomly presented by the laptop and then said aloud after each one whether they were 'true' or 'false', speaking into the microphone. Afterwards they completed the strategies questionnaire: for each sentence projected on the screen they expressed the degree of their use by pressing the number keys from 1 (very little) to 5 (very high) on the laptop keyboard. Finally they performed the Corsi, Digit Span (forward and backward version) and JND tests in a balanced order.

Results

Scoring

For the verification test, we calculated the number of correct answers (accuracy) and the response times for the correct answers. For the free recall, two independent judges scored the map drawings, awarding one point for each landmark correctly mentioned and located in the environment, i.e., participants drawn or wrote the landmark name in right location, maintaining correct relationship with others nearby (as done in previous studies; Meneghetti et al., 2009; 2013). The two independent judges' scores correlated closely ($r = .89$, $p \leq .001$), so the Experimenter's scores were used in the analysis.

Preliminary analyses

First we ascertained that the two groups (route and survey descriptions) were comparable in terms of their WM abilities, as assessed with the Corsi blocks, digit span (forward and backward order) and JND tasks. Analyses of variance showed that the two groups had similar scores in all WM measures ($F < 1$ $p = .90$ to $F = 1.40$ $p = .24$, see Table 1).

In a preliminary step, the order effects of the concurrent task (ST vs DVN vs C), type of environment (nature park vs tourist centre vs holiday farm), and recall task (verification test vs free recall) were checked by inserting each variable order as a covariate in ANCOVAs analysing: i) the effect of the secondary tasks on the primary tasks (i.e. recall accuracy in free recall and the verification test); and ii) the secondary tasks. The effects of these covariates were not significant ($F < 1$) and the ANOVAs are presented in the next paragraphs.

Insert Table 1 here

Interference effects on primary tasks

Free recall

The mixed 2 (Description: survey vs route) x 3 (Concurrent task: ST vs DVN vs C) ANOVA on the free recall scores showed only the main effect of the Concurrent task, $F(2, 116) = 13.13$, η^2_p

= .19, $p < .001$. Post hoc comparisons showed that accuracy was lower in the ST (M = 4.59, SD = 3.64) than in the C (M = 7.07, SD = 3.10, $p< .001$) and DVN (M = 6.12, SD = 3.74, p=.003) conditions; accuracy in C and DVN did not differ from one another (p=.189).

Verification test

Mixed 2 (Description: survey vs route) x 3 (Concurrent task: ST vs DVN vs C) x 2 (Sentence: survey vs route) ANOVAs were conducted on the verification test scores for accuracy and response times: only the results of accuracy are reported because no significant effects or interactions emerged for response times (F < 1 p = .96 to F = 1.60 p = .10).

The main effect of the Concurrent task was significant, F(2, 116)= 10.88, η^2_p = .16, $p < .001$, where accuracy was lower in the ST (M = 5.96, SD = 1.93) than in the C (M = 6.79, SD = 1.76) or DVN (M = 6.89, SD = 1.86; $p_s \leq .001$) conditions; no differences emerged between DVN and C ($p >.05$; see Table 2).

The two-way Sentence x Description interaction was significant, F (1, 58) = 48.78, η^2_p = .46, $p < .001$. The mean comparisons showed higher scores for accuracy in sentences expressed from the same perspective as that of the description heard: after hearing survey descriptions accuracy was better for survey sentences (M = 7.21, SD = 1.08) than for route ones (M = 5.89, SD = 1.34; $p < .001$); and after hearing route descriptions it was better for route sentences (M = 6.95, SD = 1.08) than for survey ones (M = 6.12, SD = 1.16; p = .001). This 2-way interaction was further qualified by the three-way interaction Description x Sentence x Concurrent task F(2, 116) = 3.41, η^2_p = .06, p = .036. To better elucidate this interaction, exploring the effect of each secondary task on the types of sentence and types of description, three separate ANOVAs were computed on the ST, DVN and C conditions. The means and standard deviations distinguished as a function of Description, Sentence and Concurrent tasks are given in Figure 1 and Table 2.

The Sentence x Description ANOVAs were found significant in the ST, F (1, 58) = 17.92, η^2_p = .24, $p < .001$, and DVN conditions, F (1, 58) = 35.14, η^2_p = .38, $p < .001$, but not in the C condition, F = 2.61, p =.11. The mean comparisons within each concurrent task condition (using

Bonferroni's correction, only comparisons with $p \leq .01$ were considered significant) showed that, in the ST condition, the survey description group was more accurate for survey sentences (M = 6.73 SD = 1.81) than for route sentences (M = 5.20 SD = 1.80; $p < .001$); the route description group's accuracy did not differ between the route versus survey sentences (route sentences: M = 6.47 SD = 2.00; survey sentences: M = 5.43 SD = 1.45; $p = .019$); in the DVN condition, the survey description group was more accurate for survey sentences (M = 7.58 SD = 1.42) than for route sentences (M = 6.14 SD = 1.91; $p < .001$), and the route description group was more accurate for route sentences (M = 7.66 SD = 1.51) than for survey sentences (M = 6.17 SD = 1.98; $p < .001$); in the C condition, there were no significant differences between the sentences ($p = .021$; $p = .935$). These results indicate that in the dual task (ST and DVN), but not in the C condition, recalling information from a different perspective from the one learnt is associated with a higher burden on visual and spatial WM resources.

To detect the load of the dual vs single task, we compared the accuracy of each type of sentence in each type of description in the C vs DVN and C vs ST conditions. The comparisons showed significant differences between C and ST: the route description group answered survey sentences less well in the ST (M = 5.43, SD =1.45) than in the C condition (M = 6.70, SD =2.00; $p = .004$); the survey description group likewise answered route sentences less well in the ST (M = 5.20, SD =1.80) than in the C condition (M = 6.30, SD =1.80; $p = .01$); while no difference emerged between DVN and C ($p = .02$ to $p = .61$).

Overall, these results indicate that verification test accuracy decreased in the dual task condition (in both ST and DVN) for sentences testing spatial information from a different perspective from the one learnt (i.e. for route sentences after learning survey descriptions and for survey sentences after learning route descriptions). However, only ST negatively affected accuracy by comparison with the C condition for sentences expressed from an opposite perspective from the one learnt.

Insert Figure 1 and Tables 2 here

Interference effects on secondary tasks

Spatial tapping. Two rates were calculated: 1. tapping speed in the single-task condition (number of taps in 30 seconds); and 2. tapping speed in the dual-task condition (number of taps in 360 seconds, i.e. the time it took to present the description). Comparing these rates with a mixed 2 (Tapping: single vs dual-task condition) x 2 (Description: route vs survey) ANOVA showed no significant effects or interactions ($F < 1$ to $F = 1.14$ $p= .28$); the number of taps per second was M = 0.85 (SD = .25) in the single-task condition, and M = 0.82 (SD = .21) in the dual-task condition.

Dynamic visual noise. Fixations were computed for 35 participants. The participants were included in the analyses if they showed 80% eye fixation in both the single- and the dual-task condition. Two rates were calculated: 1. number of eye fixations (80 millisec. per fixation) in the single-task condition (total number of fixations in 30 seconds); and 2. number of eye fixations in the dual-task condition (number of fixations in 360 seconds), distinguishing between the five ROIs.

Twenty-two participants reached the 80% eye fixation cut-off (10 for survey and 12 for route descriptions). The mixed 2 (Concurrent task: single- vs dual-task) x 2 (Description: route vs survey) x 5 (ROI: 1 vs 2 vs 3 vs 4 vs 5) ANOVA only showed a main effect of ROI, $F(4,80) = 323.55$, $\eta^2_p = .94$, $p < .001$, the number of eye fixations being higher in the ROI 4 - the central portion of the screen - (M = 68.99 SD = 12.16; $p < .001$) than in the other ROIs (1: M = 5.07 SD = 9.54; 2: M = 2.87 SD = 1.97; 3: M = 5.15 SD = 5.66; 5: M = 1.27 SD = 2.67), and lower in ROI 1 than in ROIs 2 and 3 ($p_s < .01$).

Strategy

The mixed 2 (Description: survey vs route) x 3 (Concurrent task: ST vs DVN vs C) x 3 (Strategy: survey vs route vs verbal) ANOVA showed the main effect of Strategy, $F(2, 116)= 28.32$, $\eta^2_p = .33$, $p< .001$ – where the survey strategy (M = 4.02, SD = 0.94) had higher ratings than the route (M = 3.19, SD = 1.21) or verbal (M = 2.97, SD = 0.88; $p < .001$) strategy, while the latter two did not differ from one another ($p = .411$)- and of Description, F(1, 58)= 8.74, $\eta^2_p = .13$, $p = .004$ – where the route group (M = 3.66, SD = 0.90)had higher ratings than the survey group (M = 3.14, SD = 1.07)-.

The two-way interaction Description x Strategy was significant F (2, 116) = 11.54, $\eta^2_p = .17$, $p \leq .001$. Comparisons of the means (considering $p \leq .01$ significant; see Table 3) showed that, for survey descriptions, participants reported a greater use ($p_s < .001$) of survey strategy (M = 4.08, SD =0.98) than of route strategy (M = 2.56, SD =1.15) or verbal strategy (M = 2.75, SD =0.91), while the latter two did not differ from one another ($p = 1.00$); for route descriptions, on the other hand, participants reported making more use of route strategy (M = 3.83, SD =0.91) and survey strategy (M = 3.94, SD =0.91), both to much the same degree ($p = 1.00$), rather than verbal strategy (M = 3.20, SD =0.80; $p_s \leq .01$).

Insert Table 3 here

Discussion and Conclusions

The main aim of the present study was to elucidate the mechanisms involved in the construction of spatial models by exploring the specific role of spatial and visual WM in learning route and survey descriptions. This was done using a dual-task paradigm to analyse whether WM allocates a sizable proportion of its resources – and its visual and spatial resources to a different extent - to supporting the perspective flexibility of spatial models.

There was a shortage of research exploring the simultaneous roles of visual and spatial WM in learning survey and route descriptions. Previous studies mainly showed that: i) spatial WM is involved in learning spatial (and especially route) descriptions, but few studies considered survey descriptions, or compared them with route descriptions (see Gyselinck & Meneghetti, 2011), and only Brunyé & Taylor (2008b) explored the role of WM in constructing perspective-flexible spatial models; and ii) visual WM is involved in verbal information processing too (Quinn & McConnell, 1996; 2006), but - here again - few studies considered both survey and route descriptions, finding a more limited involvement of visual than of spatial WM (i.e. Pazzaglia & Cornoldi, 1999; Deyzac et al., 2006). Analysing the cognitive mechanisms underlying survey and route description learning enables us to examine whether the construction of perspective-flexible spatial models relies on a different engagement of WM resources during the encoding of spatial information. This novel study explored the role of both spatial and visual WM systems in learning survey and route descriptions, and the involvement of spatial and visual WM in managing information within and across the perspectives learnt. Participants listened to survey or route descriptions while performing spatial (ST) and visual (DVN) secondary tasks (or no secondary tasks in the control condition, C), then they freely reported all the information they could remember (free recall) and said whether sentences concerning spatial relations from a survey and route view were true or false (verification test).

The results mainly showed that the allocation of WM resources changes as a function of the type of description and the type of sentence, where these effects were observable only on the primary task (recall accuracy), not on the secondary task (i.e. ST tapping speed or number of eye fixations with DVN).

The Description x Sentence x Concurrent task interaction found in the verification test is certainly the most interesting result. It shows that DVN and ST had a different impact on true/false sentence accuracy, which changed as a function of the type of sentence and the type of description learnt. It is worth noting that, in the control condition, accuracy in deciding whether sentences expressing spatial relations from the same or a different perspective from the one learnt were true or false was much the same after learning survey and route descriptions. This type of result supports the assumption that spatial models incorporate multiple perspectives, i.e. they become perspective-flexible, so that spatial information can be inferred regardless of whether it was encoded from a route or a survey perspective (Taylor & Tversky, 1992; Brunyé & Taylor, 2008a, b).

WM memory has a central role in supporting this perspective flexibility, as shown by the results seen in the DVN and ST conditions. When ST (i.e. tapping on a table with the tips of the fingers) was associated with hearing survey descriptions, accuracy was worse for sentences testing spatial relations from a route perspective as opposed to a survey perspective, whereas after hearing a route description the mean values indicate a disadvantage for sentences testing spatial relations from a survey perspective (although the differences that emerged were not statistically significant). When the DVN (watching a DVN stimulus) was associated with spatial descriptions, after hearing a survey or route description, accuracy was worse for sentences testing spatial relations from a different perspective from the one learnt than for sentences testing spatial relations from the same perspective. This indicates that answering true/false questions testing spatial relations from a different perspective from the one learnt places a greater burden on spatial and visual WM resources than when dealing with sentences expressing spatial relations from the same perspective as the one learnt. So extracting information from a different perspective from the one learnt is possible, which means that mental representations can incorporate multiple views, but at an extra cost in terms of WM resources.

It is noteworthy, however, that comparisons devoted to assessing the interference produced by the dual task as opposed to the single task showed that only the ST condition prompted a loss of recall accuracy by comparison with the control condition for sentences expressed from the opposite perspective from the one learnt, i.e. accuracy was worse for survey sentences after hearing route descriptions, and for route sentences after hearing survey descriptions. No differences emerged between the DVN and C conditions. In free recall too, accuracy was worse in the ST than in the C condition, while no differences were found between C and DVN. This finding further contributes to showing that spatial WM is especially involved when spatial information needs to be actively recalled (free recall task), and retrieved from the opposite perspective to the one learnt (verification test). This does not happen for visual WM, since the DVN prompted no loss of recall accuracy vis-à-vis the single-task condition, even though we ensured that participants had watched the screen, and the central area (ROI 4) in particular, and the DVN stimulus had been made more powerful (as in Dean et al., 2008).

Our innovative results show that both spatial and visual WM are involved in supporting the construction of spatial models from route and survey descriptions, and the involvement of WM is stronger when spatial information needs to be extracted across-perspectives. Both spatial and visual WM support the switch from the perspective acquired while learning to another used during recall testing (and not learnt directly). It is noteworthy, however, that the specific effect of loading induced by a secondary task, with a loss of accuracy in the dual-task with respect to the single-task condition, was evident for ST but not for DVN.

Although these findings are new and interesting, some considerations are needed on how our results concerning the involvement of spatial and visual WM differ from those of previous works.

Concerning the role of spatial WM, our results contrast with previous findings in that they showed a more pronounced spatial WM involvement in spatial models derived from route descriptions (Pazzaglia et al., 2010), even when across-perspective sentences were assessed (Brunyé & Taylor, 2008b). The differences between our findings and those of Brunyé & Taylor (2008b) can be partly attributable to: different materials, procedures, and experimental design (the type of concurrent task used was within participants here as opposed to between participants in Brunyé & Taylor, 2008b); the text presentation method (oral here vs visual, sentence by sentence, in Brunyé & Taylor, 2008b); the number of times the text was presented (twice here vs three times in Brunyé & Taylor, 2008b); the length of the descriptions (shorter here, with 285-319 words; longer, with 483-755 words in Brunyé & Taylor, 2008b). These variables, and possibly others too, could concur in generating differences in the involvement of spatial WM in processing survey and route descriptions. It may be that a combination of such factors produced a strong engagement of spatial WM resources in our setting, especially when it came to managing spatial information from different perspectives from the one learnt. Though plausible, such speculation needs to be substantiated by collecting further data in order to better analyse the cognitive mechanisms involved in the construction of spatial models and in ensuring their perspective flexibility.

Our findings concerning the involvement of visual WM warrant a different comment. The interference effect produced by DVN demonstrates the involvement of visual WM, demonstrating that visual resources support the generation of mental images derived from spatial descriptions. The idea that spatial models can be configured as mental images of the environment (Denis & De Vega, 1993) is substantiated by the scores for strategy use. Learning spatial descriptions relied more on visualizing the path and/or map of the environment than on verbal repetition of the information (as previously demonstrated by Meneghetti, De Beni et al., 2011; Meneghetti et al., 2013); this visualization process loads the visual WM, as shown previously by studies based on visualizing words (Quinn & McConnell, 2006), with the novelty that this involvement was detected during the formation of mental images referring to environments acquired from verbal descriptions. Even if these results are encouraging, supporting the idea that visual WM is engaged in the construction of spatial models, its role was not similar to that of spatial WM (as we can see from our finding no difference between the DVN and the C conditions); this difference found in the effects of visual and spatial secondary tasks on environment description learning is consistent with studies showing that visual WM has a much smaller role than spatial WM in survey and route description processing (Pazzaglia & Cornoldi, 1999; Deyzac et al., 2006). But before we conclude that the role of visual WM in spatial description processing is only marginal, we need to consider other factors such as the type of concurrent task used. It may be that DVN is not strong enough to interfere with the processing of complex material (even though we increased the complexity of our DVN stimulus by making 50% of the dots change per second and we monitored participants’ eye fixation on the screen). The use of other visual secondary tasks (such as the presentation of a series of line drawings; Borst et al., 2012) may be more sensitive in detecting the role of visual WM in visuo-spatial information processing, such as environment descriptions. Stressing the use of imagery strategies to process information (by giving explicit instructions to use mental images, as in Quinn & McConnell, 2006; and Borst et al., 2012), rather than simply having participants spontaneously report their strategy use (as in the present study) might enable us to better qualify the involvement of visual WM.

Finally, some specific considerations are due on our results relating to strategy use. Our analysis showed that participants' strategy use ratings changed as a function of the type of description, not of the concurrent task condition. For survey descriptions, participants reported using survey strategy more than route or verbal strategy, while for route descriptions they made more use of spatial strategies (both survey and route) than of verbal ones. These results confirm that verbal strategy were used less than those based on visualization (as in Meneghetti et al., 2013; 2011), and that survey descriptions spontaneously induce the use of strategies based on visualizing a map, while route descriptions seem to prompt a greater use of strategies based on visualizing paths and maps of an environment. Participants' ratings were not influenced by WM load, but before we rule out any change in rated strategy use as a function of WM load (given the paucity of knowledge available), future studies should better explore the role of strategy use and how it may change with the loading of visual and spatial WM during spatial description learning.

To conclude, the findings of the present study contribute to broadening our theoretical knowledge of the properties of spatial models and the cognitive mechanisms involved in their formation, particularly analysing the role of visual and spatial WM during the learning of survey and route descriptions. Our findings indicate that spatial models are abstractions of content in which spatial information can be visualized from different perspectives and WM defines the basis for forming perspective-flexible spatial models. Indeed, both visual and spatial WM support the processing of survey- and route-based spatial information, and are further involved (especially spatial WM) when spatial information needs to be managed and extracted from a different perspective from the one encoded.

References

Baddeley, A. D. (1986). Working Memory. Oxford: Oxford University Press.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? Trends in Cognitive Science, 4, 417-423. doi: 10.1016/S1364-6613(00)01538-2.

Borst, G., Niven, E., & Logie, R. H. (2012) Visual mental image generation does not overlap with visual short-term memory: A dual-task interference study. Memory and Cognition, 40, 360-372. doi 10.3758/s13421-011-0151-7.

Brunyé, T. T., & Taylor, H. A. (2008a). Extended experience benefits spatial mental model development with route but not survey descriptions. Acta Psychologica, 127, 340-354. doi: 10.1016/j.actpsy.2007.07.002.

Brunyé, T. T., & Taylor, H. A. (2008b). Working memory in developing and applying mental models from spatial descriptions. Journal of Memory and Language, 58, 701-729. doi: 10.1016/j.jml.2007.08.003.

Cornoldi, C., & Vecchi, T. (2003). Visuo-spatial Working Memory and Individual Differences. Psychology Press, Philadelphia.

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain [Doctoral dissertation]. Montreal: McGill University.

Dean, G. M., Dewhurst, S. A., Whittaker, A. (2008). Dynamic visual noise interferes with storage in visual working memory. Experimental Psychology, 55, 283-289. doi: 10.1027/1618-3169.55.4.283.

De Beni, R., & Moè, A. (2003). Presentation modality effects in studying passages. Are mental images always effective? Applied Cognitive Psychology, 17, 309-324. doi: 10.1002/acp.867.

De Beni, R., Pazzaglia, F., Gyselinck, V., & Meneghetti, C. (2005). Visuo-spatial working memory and mental representation of spatial descriptions. European Journal of Cognitive Psychology, 17, 77-95. doi: 10.1080/09541440340000529.

Denis, M., & de Vega, M. (1993). Modèles mentaux et imagerie mentale [Mental model and mental imagery]. In M.F. Ehrlich, H. Tardieu, M. Cavazza (Eds.), Les Modèles Mentaux: Approche Cognitive des Représentations, (pp. 79-100). Paris: Masson.

Deyzac, E., Logie, R. H., & Denis, M. (2006). Visuospatial working memory and the processing of spatial descriptions. British Journal of Psychology, 97, 217-243. doi: 10.1348/000712605X67484.

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T.,& Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. Intelligence, 34, 151–176. doi:10.1016/j.intell.2005.09.005.

Johnson-Laird, P. N. (1983). Mental Models: Towards a Cognitive Science of Language, Inference and Consciousness. Cambridge: Harvard University Press.

Logie, R. H. (1995). Visuo-Spatial Working Memory. UK: Lawrence Brlbaum Associates Ltd.

Logie, R. H., & Marchetti, C. (1991). Visuo-spatial working memory: visual, spatial or central executive? In R.H. Logie & M. Denis (Eds.), Mental Images in Human Cognition (pp. 105-115). Amsterdam: North Holland.

Gyselinck, V., De Beni, R., Pazzaglia, F., Meneghetti, C., & Mondoloni, A. (2007). Working memory components and imagery instructions in the elaboration of a spatial mental model. Psychological Research, 71, 373-382. doi:10.1007/s00426-006-0091-1.

Gyselinck, V., & Meneghetti, C. (2011). The role of spatial working memory in understanding verbal descriptions: a window onto the interaction between verbal and spatial processing. In A. Vandienrendonck & A. Szmalec (Ed.), Spatial Working Memory (pp. 159-180). Psychology Press, Portfolio.

McConnell, J., & Quinn, J. G. (2004). Complexity factors in visuo-spatial working memory. Memory, 4, 338-350. doi: 10.1080/09658210344000035.

Meneghetti, C., Borella, E., Muffato, V., Pazzaglia, F. & De Beni, R. (2014). Environment Learning from Spatial Descriptions: The Role of Perspective and Spatial Abilities in Young and Older Adults. In C. Freksa et al. (Eds.): Spatial Cognition 2014, LNAI 8684, pp. 30–45. DOI: 10.1007/978-3-319-11215-2_12. ISBN: 978-3-319-11214-5.

Meneghetti, C., De Beni, R., Gyselinck, V., & Pazzaglia, F. (2011). Working memory involvement in spatial text processing: what advantages are gained from extended learning and visuo-spatial strategies? British Journal of Psychology, 102, 499-518. doi:10. 1111/j.2044-8295.2010.02007.x.

Meneghetti, C., De Beni, R., Gyselinck, V., & Pazzaglia, F. (2013). The joint role of spatial ability and imagery strategy in sustaining the learning of spatial descriptions under spatial interference. Learning and Individual Difference, 24, 32-41. doi: 10.1016/j.lindif.2012.12.021.

Meneghetti, C., Gyselinck, V., Pazzaglia, F., & De Beni, R. (2009). Individual differences in spatial text processing: high spatial ability can compensate for spatial working memory interference. Learning and Individual Differences, 19, 577-589. doi:10.1016/ j.lindif.2009.07.007.

Meneghetti, C., Labate, E., Ronconi, L., Grassano, M., Pazzaglia, F. (2014). The role of visuospatial and verbal abilities, styles and strategies in predicting visuospatial description accuracy. Learning and Individual Differences. 36, 117-123. Doi: 10.1016/j.lindif.2014.10.019.

Meneghetti, C., Pazzaglia, F., & De Beni, R. (2011). Spatial mental representations derived from survey and route descriptions: when individuals prefer extrinsic frame of reference. Learning and Individual Differences, 21, 150-157. doi:10.1016/j.lindif.2010.12.003.

Montello, D. R., Waller, D., Hegarty, M., & Richardson, A. E. (2004). Spatial memory of real environments, virtual environments, and maps. In G. Allen (Ed.). Human Spatial Memory:

Remembering Where (pp. 251-285). Mahwah, NJ: Lawrence Erlbaum Associates.

Pazzaglia, F., & Cornoldi, C. (1999). The role of distinct components of visuo-spatial working memory in the processing of texts. Memory, 7, 19-41. doi: 10.1080/741943715.

Pazzaglia, F., Meneghetti, C., De Beni, R., & Gyselinck, V. (2010). Working memory components in survey and route spatial text processing. Cognitive Processing, 11, 359-369. doi:10.1007/s10339-009-0353-0.

Perrig, W., & Kintsch, W. (1985). Propositional and situational representations of text. Journal of Memory and Language, 24, 503-518. doi: 10.1016/0749-596X(85)90042-7.

Phillips, L., & Hamilton, C. J. (2001). The working memory model in adult aging research. In Andrade (Ed.), Working Memory in Perspective (pp. 101-118). Hove, UK: Psychology Press.

Quinn, J. G., & McConnell, J. (1996). Irrelevant pictures in visual working memory. Quarterly Journal of Experimental Psychology, 49, 200-215. doi: 10.1080/713755613.

Quinn, J. G., McConnell, J. (2006). The interval for interference in conscious visual imagery. Memory 14, 241-252. doi: 10.1080/09658210500210019.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. The Quarterly Journal of Experimental Psychology, 62, 1457 – 1506. doi: 10.1080/17470210902816461.

Salway, A. F. S., & Logie, R. H. (1995). Visuo-spatial working memory, movement control, and executive demands. The Quarterly Journal of Experimental Psychology, 41, 107-122. doi: 10.1111/j.2044-8295.1995.tb02560.x.

Taylor, H. A., & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. Journal of Memory and Language, 31, 261-292. doi: 10.1016/0749-596X(92)90014-O.

Wechsler, D. (1981). Wechsler Adult Intelligence Scale (rev. ed.). New York: Psychological Corporation.

Figure 1. Means and standard deviations accuracy by Concurrent task (Spatial tapping vs Dynamic visual noise vs Control), Description (survey vs route) and Sentence (Survey vs Route).

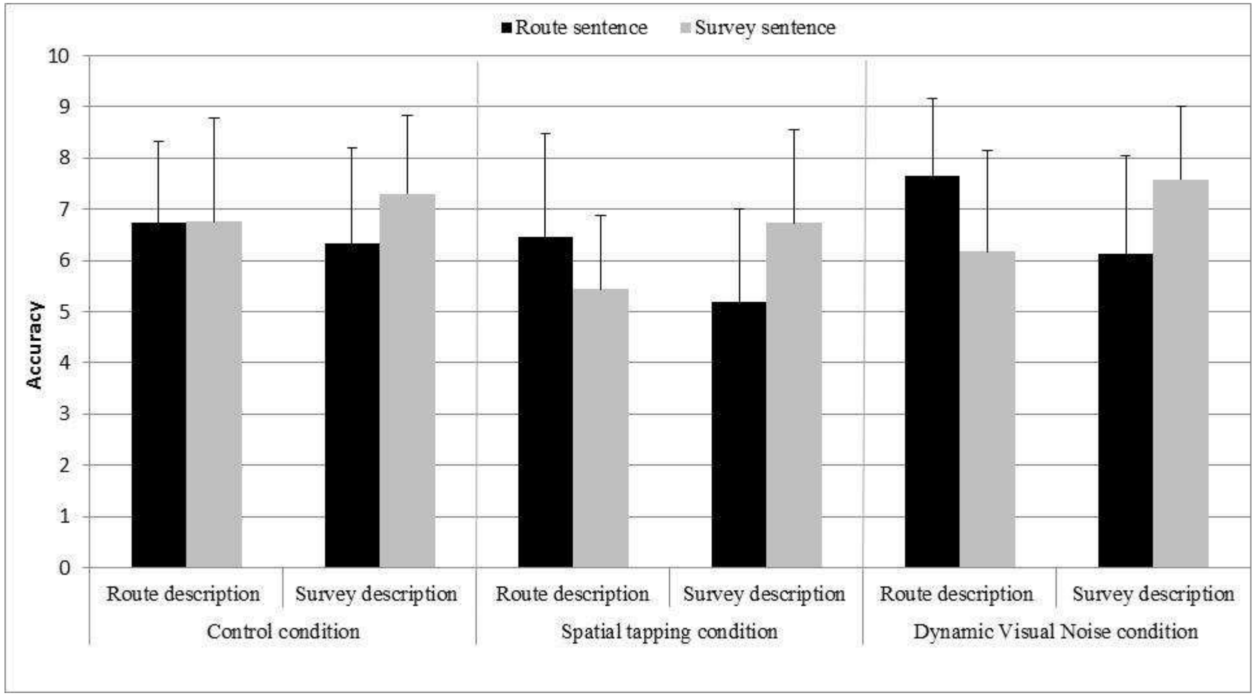

Table 1. Means and standard deviations of WM tasks by survey and route description group.

Measures	Route description group		Survey description group	
	M	SD	M	SD
Digit span (Forward)	6.20	0.96	6.23	1.10
Digit span (Backward)	4.70	1.26	4.6 7	1.09
Corsi span (Forward)	6.40	1.04	6.07	.98
Corsi span (Backward)	5.63	1.40	5.40	1.35
JND	69.20	7.02	70.64	9.91

Note: No significant differences were found between survey and route description groups.

Table 2. Means and standard deviations of accuracy by Concurrent task (Spatial tapping vs Dynamic Visual Noise vs Control), Description (survey vs route) and Sentence (Survey vs Route).

	Control condition				Spatial tapping condition				Dynamic visual noise condition				Total			
	Route sentence		Survey sentence		Route sentence		Survey sentence		Route sentence		Survey sentence		Route sentence		Survey sentence	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Route description group	6.73	1.59	6.76	2.01	6.47	2.00	5.43	1.45	7.66	1.51	6.17	1.98	6.95	1.08	6.12	1.16
Survey description group	6.33	1.86	7.30	1.53	5.20	1.80	6.73	1.81	6.14	1.91	7.58	1.42	5.89	1.34	7.21	1.08

Table 3. Means and standard deviations of strategies self-reported by Description (survey vs route), Concurrent task (Spatial tapping vs Dynamic visual noise vs Control) and Strategies (survey, route, verbal).

		Control condition		Spatial tapping condition		Dynamic visual noise condition		Total	
		M	SD	M	SD	M	SD	M	SD
Route description group	Survey strategy	3.82	1.18	4.17	1.02	3.86	1.14	3.94	0.91
	Route strategy	3.88	1.24	3.83	1.26	3.76	1.01	3.83	0.91
	Verbal strategy	3.07	1.04	3.27	0.94	3.26	1.10	3.20	0.80
Survey description group	Survey strategy	4.25	1.07	3.97	1.16	4.04	1.09	4.08	0.98
	Route strategy	2.54	1.24	2.59	1.32	2.56	1.24	2.56	1.15
	Verbal strategy	2.79	0.99	2.75	1.25	2.70	1.01	2.75	0.91

Highlights

- Visual and spatial working memory (WM) involvement in spatial description processing.
- Spatial descriptions heard while performing visual and spatial secondary tasks.
- Spatial and visual WM are involved in forming perspective-flexible spatial models.
- Survey and route description learning is associated with the use of imagery strategy.