

Mental representations derived from spatial descriptions: the influence of orientation specificity and visuospatial abilities

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Abstract This study aimed to investigate the orientation dependence effect and the role of visuospatial abilities in mental representations derived from spatial descriptions. The analysis focused on how the orientation effect and the involvement of visuospatial abilities change when survey and route descriptions are used, and the initial and main orientation of an imaginary tour. In Experiment 1, 48 participants listened to survey or route descriptions in which information was mainly north-oriented (matching the initial heading and main direction of travel expressed in the description). In Experiment 2, 40 participants listened to route descriptions in which the initial orientation (north-oriented) was mismatched with the main direction of travel (east-oriented). Participants performed pointing task while facing north vs south (Exp. 1 and 2), and while facing east vs west (Exp. 2), as well as a map drawing task and several visuospatial measures. In both experiments, the results showed that pointing was easier while facing north than while facing south, and map drawings were arranged with a north-up orientation (with no difference between survey and route descriptions). In Experiment 2, pointing while facing east was easier than in the other pointing conditions. The results obtained with the visuospatial tasks showed that perspective-taking (PT) skill was the main predictor of the ability to imagine positions misaligned with the direction expressed in the descriptions (i.e. pointing while facing south in Experiment 1; pointing while facing north, south or west in Experiment 2). Overall, these findings indicate that mental representations derived from spatial descriptions are specifically oriented

and their orientation is influenced by the main direction of travel and by the initial orientation. These mental representations, and the adoption of counter-aligned imaginary orientations, demand visuospatial skills and PT ability in particular.

Introduction

Spatial learning and orientation specificity: the case of spatial descriptions

Knowledge of spatial relations can frequently be acquired directly (through sensorimotor experience) or indirectly, e.g. using maps or virtual displays (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Montello, Waller, Hegarty, & Richardson, 2004, for a review), or descriptions (Gyselinck & Meneghetti, 2011, for a review). In the latter case, people read or hear a description of an environment and create a mental model, i.e. an internal representation that resembles the structure of the corresponding state of affairs in the outside world (Johnson-Laird, 1983), preserving the physical properties of space, i.e. the relationships between objects and information about distances (Morrow, Stine-Morrow, Leirer, Andrassy, & Kahn, 1997; Rinck, Hahnel, Bower, & Glowalla, 1997).

Spatial description studies—mostly in the mental model domain—have focused on how different variables (such as goals, reading times, and so on) influence the features of mental representations (e.g. Brunye & Taylor, 2008). Other studies coming from the spatial cognition domain and inspired by studies using visual inputs (e.g. Presson, Delange, & Hazelrigg, 1987, 1989; Presson & Hazelrigg, 1984; Richardson, Montello, & Hegarty, 1999; Shelton &

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McNamara, 2001) have explored how spatial information conveyed by descriptions is ultimately organized in the memory. On the whole, these studies (Shelton & McNamara, 2004; Wilson, Tlauka & Wildbur, 1999; Wilson & Wilbur, 2004) have shown that mental representations derived from spatial descriptions are memorized according to a preferred point of view, usually aligned with an imaginary viewpoint experienced; this property of mental representation is called orientation dependence. The learning perspective could have an important influence on the properties of mental representations. The learning perspective is the way in which spatial information is conveyed, and is classically distinguished as a survey perspective (a bird's eye view, using canonical terms) and a route perspective (a person's point of view, using egocentric terms) (Perrig & Kintsch, 1985; Taylor & Tversky, 1992). The frame of reference used to convey spatial information (survey vs route) may be related to how the information is mentally organized in the memory, i.e. the preferred orientation adopted for the mental representation. To our knowledge, however, few studies have explored orientation dependence in relation to learning perspective. In a first study, Wilson et al. (1999, Experiment 1) asked participants to read descriptions of simple paths (the U-shaped path by Presson et al., 1987, 1989) that presented information from an aerial or personal viewpoint (resembling survey or route perspectives) and all paths had the same starting point with a north-up orientation aligned with the learner's imaginary viewpoint. The dependent measure used (as is generally the case in orientation dependence studies using visual input, e.g. Presson et al., 1987, 1989) was a pointing task (also called 'judgment of relative direction'), in which participants imagine being at a certain landmark in an environment while facing another and pointing at a third that may be aligned (i.e. north-up oriented) or counter-aligned with the learner's imaginary viewpoint. The results showed that participants performed better in aligned than in counter-aligned pointing, with no differences between survey and route perspectives. The orientation effect was confirmed with descriptions presenting a large-scale environment (Wilson et al., 1999; Experiment 2) and adding salient landmarks (Wildbur & Wilson, 2008), though the authors used simplified path descriptions (as in the Presson et al. configuration). Shelton and McNamara (2004) approached orientation dependence in relation to the survey and route perspectives with more realistic open environments (adapted from Taylor & Tversky, 1992), asking participants to learn verbally-presented and virtually-reproduced environments (Experiment 1), and then testing the properties of their mental representations using scene recognition tasks (which involved discriminating between images in different orientations). Their results showed that 0°-oriented images (i.e. aligned with the learner's imaginary viewpoint) were

recognized better than other orientations (not aligned with the learner's viewpoint) after hearing survey and route descriptions, and after seeing survey movies, but not after seeing route movies (when they performed better with images consistent with the first leg of the route shown in the movie). These results clearly indicated that performance was better for the 0° orientation than for the other imagined orientations. To reinforce their findings on the orientation effect in relation to learning perspective, the authors used a pointing task that (unlike scene recognition) is a more direct measure of spatial memory uninfluenced by visual cues (Shelton & McNamara, 2004). Virtual explorations (not descriptions) were proposed using survey and route perspectives (Shelton & McNamara, 2004; Experiment 3) and the results again clearly showed that mental representation is north-up oriented after learning survey and route virtual environments. The authors concluded that mental representations are orientation-dependent and the initial view is decisive in determining how the information is organized in the memory, and to much the same extent when spatial information is encoded from a survey or route perspective. In the Shelton & McNamara study (2004) the beneficial effect of the initial orientation on the overall organization of the representation (tested using a pointing task) emerged with visual explorations, however, while the orientation effect (using a pointing task) when the initial input is in the form of realistic descriptions has yet to be ascertained. In fact, the orientation dependence (tested with a pointing task) that emerged for virtual (visual) survey and route tours (Shelton & McNamara, 2004; see also Wilson & Wilbur, 2004) may not necessarily be extendable a priori to spatial descriptions. In Shelton and McNamara (2004), moreover, the starting heading coincided with the primary direction of travel, i.e. the starting point was in the south-west corner and the virtual tour began by moving northwards, then continued with south-, west- and eastward orientations (changing the heading for the route perspective, but not for the survey perspective). The first aim of our study was consequently to extend the analysis of the orientation effect on mental representations derived from spatial descriptions of open environments (similar to the one used by Shelton & McNamara, 2004; but differing from the simple path configuration used by Wilson and colleagues), testing the orientation effect by means of aligned and counter-aligned pointing tasks (as used by Wilson and colleagues, but not by Shelton & McNamara, 2004). Our study also aimed to ascertain whether the orientation of a mental representation is influenced mainly by its initial orientation (as suggested by Shelton & McNamara, 2004; Wilson et al., 1999; Wilson & Wilbur, 2004) and also by the main direction of an imaginary tour. These issues were approached in Experiments 1 and 2, and also explored in relation to individual visuospatial abilities (as a second aim).

Spatial learning and individual differences

Analyzing the role of individual visuospatial factors helps to explain individual variability in mental representations of environments derived from visually-acquired information (Allen, Kirasic, Dobson, Long, & Beck, 1996; Hegarty et al., 2006; see Wolbers & Hegarty, 2010; for a review) and descriptions (Meneghetti, Pazzaglia, & De Beni, 2011; see Pazzaglia, Gyselinck, Cornoldi, & De Beni, 2012 for a review). A key factor in exploring visuospatial abilities in relation to spatial descriptions is mental rotation (MR) i.e. the ability to rotate three-dimensional stimuli. A greater MR ability is related to a better performance in recall tasks (such as map drawing tasks and verification tests) after learning spatial descriptions (from both survey and route perspectives; e.g. Meneghetti, Gyselinck, Pazzaglia, & De Beni, 2009; Pazzaglia, 2008). Another related spatial ability involved in processing spatial descriptions is visuospatial working memory (VSWM), a system involved in retaining and processing spatial information (Logie, 1995). Individuals with a higher spatial span (measured with the Corsi blocks task, Corsi, 1972) have a better spatial text recall after learning spatial descriptions (from both survey and route perspectives; e.g. Meneghetti, Pazzaglia et al., 2011; Pazzaglia & Cornoldi, 1999; Gyselinck, Cornoldi, Dubois, De Beni, & Ehrlich, 2002). These findings go to show that MR and VSWM are two spatial cognitive abilities that are related to one another (e.g. Meneghetti et al., 2009), and they are fundamental to the formation of a good spatial mental representation.

More recent studies have shown that self-reported spatial preferences are also related to accuracy in spatial descriptions (Meneghetti, Pazzaglia et al., 2011; Pazzaglia & Meneghetti, 2012). Pazzaglia and Meneghetti (2012) found, for instance, that spatial preferences in orienting oneself and spatial abilities (including MR) are the main predictors of performance in recalling survey and route descriptions (see also Meneghetti, Ronconi, Pazzaglia, & De Beni, 2013).

Overall, the above-mentioned studies indicate that self-reported orientation strategies and visuospatial abilities (such as MR and VSWM) are relevant individual skills that are involved (to varying degrees) in mental representations derived from spatial descriptions. These cognitive and self-reported competences are related to one another: MR is related to VSWM (Meneghetti et al., 2009) and orientation strategy (Meneghetti, Pazzaglia et al., 2011; Pazzaglia & De Beni, 2001; 2006; Shelton & Gabrieli, 2004); and orientation strategy is related to VSWM (Baldwin & Reagan, 2009; Meneghetti et al., 2013). Performance in pointing tasks is also related to visuospatial skills (Lawton, 1996; Meneghetti, Pazzaglia et al., 2011; Pazzaglia & De Beni, 2006). For example, Pazzaglia and De Beni (2006) showed

that, after map learning, higher MR individuals were better able to take a counter-aligned view (i.e. they were less susceptible to the orientation dependence effect) than people with weaker MR skills.

On the other hand, there is no evidence of how visuospatial abilities modulate the orientation effect after learning survey and route descriptions. Some indirect evidence comes from Fields and Shelton (2006), who explored individual visuospatial abilities in virtual environments presented from a survey or route perspective: the results of a pointing task (testing imaginary headings ranging from 0°—aligned with the learner’s view—to 315°) confirmed the orientation effect. When individual spatial differences were analyzed, the best predictors for both types of perspective were tasks measuring MR ability and perspective-taking (PT) ability (tested with the OPT proposed by Kozhevnikov & Hegarty, 2001, which measures the ability to imagine adopting misaligned positions in an object configuration), followed by a spatial span and left/right map directions task (measuring the ability to give left/right directions misaligned with the observer’s viewpoint). But the key factor involved in changes of heading orientation is PT.

Therefore, our second aim was to examine whether visuospatial abilities (distinguishing between mental rotation, perspective-taking, VSWM and self-reported spatial preferences) have a relevant role in supporting mental representations derived from survey and route descriptions (and not only in those derived from virtual explorations, as shown by Fields & Shelton, 2006), and whether all or only some visuospatial competences (like the PT ability identified by Fields & Shelton, 2006) are associated with the orientation effect and learning perspective.

To sum up, in accordance with the theoretical premises, we approached the following questions:

- Given that the orientation effect has yet to be explored systematically using spatial descriptions as input in relation to spatial perspectives and the initial orientation or main direction of the information presented (few studies have approached these issues, i.e. Wilson et al., 1999; Shelton & McNamara, 2004), we investigated (as our first aim) whether mental representations derived from spatial descriptions are susceptible to the orientation effect, and how this effect relates to the modality used to express information, operationalized in terms of the perspective learnt (in Experiment 1), the initial orientation of the descriptions and the main direction of an imaginary tour (in Experiment 2);
- Given that visuospatial abilities are acknowledged an important role in the construction of mental representations derived from spatial descriptions from both survey and route perspectives (e.g., Pazzaglia et al.,

2012), we investigated (as our second aim) whether all or only some visuospatial abilities are related to the orientation of the information gained from survey and route descriptions. This question was approached in both Experiments 1 and 2.

Experiment 1

In Experiment 1, as a first aim, mental representations derived from descriptions of open environments presented from survey and route perspectives and initially oriented north-up—which coincided with the main direction of travel—(similar to those used by Shelton & McNamara, 2004), were tested in terms of their orientation features using pointing tasks (whereas Shelton & McNamara, 2004 used survey and route descriptions, but employed a recognition task to test the mental representations); as a second aim, we considered the influence of visuospatial abilities on the orientation features of mental representations derived from survey and route descriptions.

In Experiment 1, participants listened to environment descriptions conveying information from a survey perspective (expressing spatial relations between landmarks using canonical terms), and from a route perspective (expressing spatial relations from a person's point of view), in which information was expressed mainly going from south to north. Spatial memory was assessed by using pointing tasks and testing northwards and southwards positions. A verbal task in the form of a reading comprehension task was administered for control purposes, and visuospatial tasks were used to measure MR and VSWM abilities (using the MRT and Corsi blocks task, respectively), given the relevance of their role emerging from previous studies using descriptions (Meneghetti et al., 2009; Pazzaglia, 2008). PT ability was measured too (with the OPT and left/right map directions tasks) because of its importance to orientation independence in virtual environment learning (Fields & Shelton, 2006). Participants' self-assessments of their sense of direction and spatial representations were also recorded (using the SDSR scale; Pazzaglia, Cornoldi & De Beni, 2000) to better elucidate the relationship between spatial self-assessments and spatial descriptions (as found in Meneghetti, Pazzaglia et al., 2011; Meneghetti et al., 2013; Pazzaglia & Meneghetti, 2012).

Concerning the orientation effect (our first aim), Experiment 1 explored whether the way in which information is organized in the memory according to a preferred orientation (i.e. the orientation dependence effect) is related to the learning perspective. Given the important role of the initial imaginary orientation (facing north) in

influencing the whole representation (as found by Shelton & McNamara, 2004; Wilson et al., 1999), we expected to find that spatial information is memorized according to a preferred orientation after learning a description from a survey or route perspective. This would corroborate the theoretical assumption that spatial information is memorized according to a preferred orientation [as concluded in studies using verbal input (Shelton & McNamara, 2004) and visual input (Fields & Shelton, 2006)]. So, if the orientation dependence is confirmed for both types of description, then performance should be better in pointing tasks testing imaginary north-facing positions than when the task involves pointing southwards; and map drawings should be mainly north-up oriented. We focused on whether the learning perspective affects the representation, i.e. whether one perspective modulates the orientation effect more than the other. If this were the case, then there would be differences in pointing performance while facing south and north for descriptions learnt from a survey as opposed to a route perspective.

Concerning visuospatial abilities and the orientation effect (our second aim), Experiment 1 explored whether certain visuospatial abilities, such as MR and PT, influence mental representations (as previously suggested by Fields & Shelton, 2006, using visual input, but newly analyzed here using spatial descriptions), and whether their influence changes as a function of the spatial perspective learnt and the imaginary orientation being tested. Given that processing route and survey descriptions demands different cognitive resources (such as working memory, Meneghetti, De Beni et al., 2011) and individual spatial competences (such as orientation strategies Meneghetti, Pazzaglia et al., 2011), it may be that different visuospatial abilities are involved in supporting the orientation of mental representations stemming from route and survey descriptions.

Method

Participants

The study involved 48 university students (23 males; mean age 24.2 years), half of them assigned to hearing a description from a route perspective (12 males), the other half (11 males) from a survey perspective.

Material

Visuospatial and verbal measures

Mental rotations test (MRT, Vandenberg & Kuse, 1978). This comprises 20 items, each showing a 3D target figure and four possible matching figures (assembled cubes). The

task consists in finding two figures identical to the target but rotated in space (time limit: 8 min).

Object perspective task (OPT, Kozhevnikov & Hegarty, 2001; Hegarty & Waller, 2004). This comprises a configuration of 8 objects and 12 sentence items listed under the object configuration, each with a circle in which to indicate the answer. For each item, participants are asked to imagine standing at one object within a configuration, facing another, and pointing to a third; the answer is given (with the object configuration still available) by drawing an arrow from the center to the edge of the circle; a straight line going from the center to the perimeter of the circle joins the object where participants imagine standing to the object they are facing. All items require a greater than 90° change of perspective. The time limit is 5 min.

Spatial indication task (SIT, Nori & Giusberti, 2003). This involves the use of a 2D map of a fictitious city on which a route is marked. Participants say aloud which left or right turns to take from a starting point to a destination without rotating the map (total turns 17, no time limit).

Reading comprehension task (RCT, Cornoldi, Rizzo, & Pra Baldi, 1991). This consists of reading an abstract text and answering ten multiple-choice questions with the text available for consultation (no time limit).

Working memory (WM) measures. The Corsi Blocks task (Corsi, 1972) involves reproducing sequences of blocks arranged irregularly on a board; the digit span task (Wechsler, 1981) entails reiterating a sequence of digits. Participants had to reproduce increasingly long sequences of blocks/digits in forward or reverse order. In both measures, the length of the sequence varied from 2 to 9 blocks/digits (and two sequences were used for each length).

Sense of Direction and Spatial Representation Scale (SDSR; Pazzaglia et al., 2000). This comprises 11 items measuring general sense of direction, knowledge and use of cardinal points, and preference for survey, route or landmark-focused representations. Answers are given on a Likert scale of 1–5; reliability is $\alpha = .75$ (for more details, see Pazzaglia & De Beni, 2001).

Spatial descriptions

Two descriptions of an open environment (“the Zoo”) were prepared from a route and a survey perspective. The two descriptions were of similar length (260 and 271 words for the survey and route perspectives, respectively). The Zoo contained nine landmarks (entrance, ticket booth, elephants, playground, fountain, ice-cream parlor, chimpanzees, lions, and dolphins) located inside a square, with four in the corners, four halfway between two corners and one in the center (see Fig. 1).

Both types of description provide general information about the Zoo (e.g. the Zoo is an outdoor area, the landmarks are 100 m apart), and explain the landmarks’ layout from south to north according to a person’s point of view (route perspective) or from a bird’s eye view (survey perspective); a pilot study had previously ascertained that both types of description were recalled equally well.

In the route version (using egocentric terms), listeners were asked to imagine walking along a path going from the entrance gate (located in the bottom left-hand corner) towards the playground, and beyond it to reach the chimpanzees (this was called Leg 1, with north-up oriented information). Then they had to imagine turning twice through 90° on the path that goes from the lions towards the fountain, and from there to the ticket booth (Leg 2, south-oriented). Finally, they had to imagine turning twice through 90° on the path going from the elephants towards the ice-cream parlor, and arriving at the dolphins (Leg 3; north-up; see the path in Fig. 1).

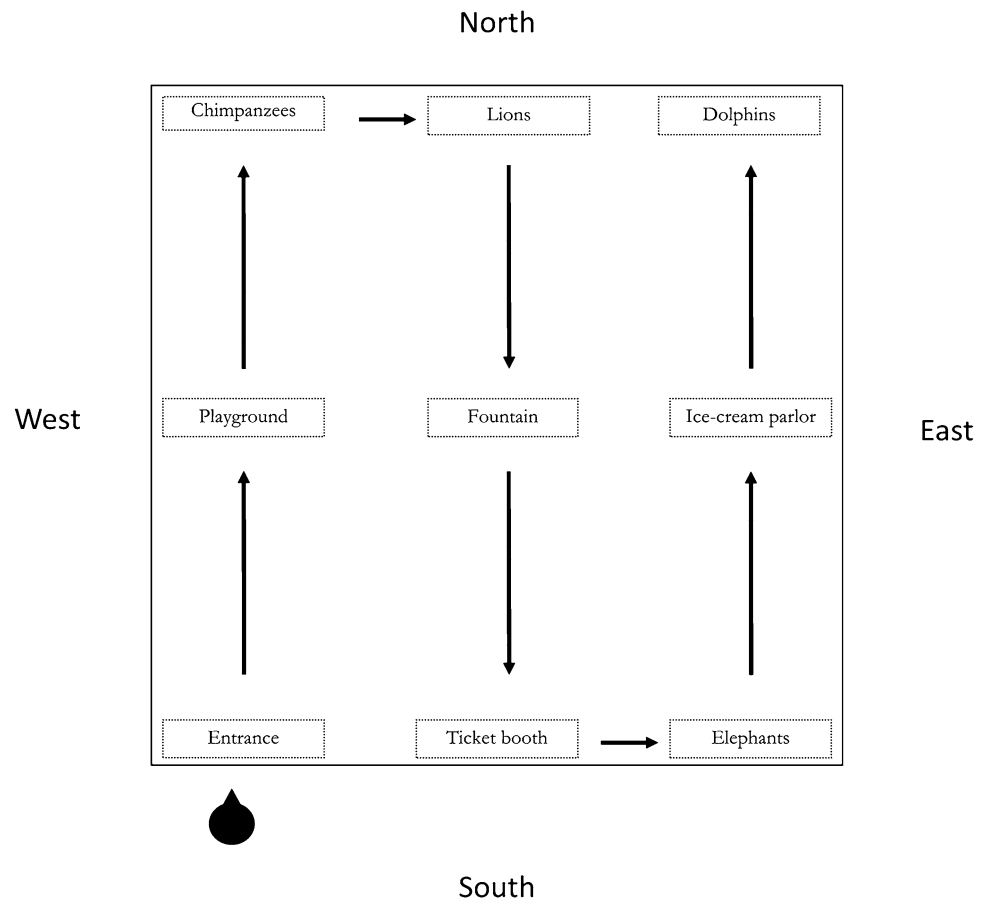
In the survey version (using canonical terms, such as “south”, “north-east”, etc.), the landmarks’ locations were presented from south to center, to north as follows: listeners were asked to imagine the landmarks located along the south side of the area showing the entrance (in the south-west corner), then the ticket booth (in the center of the south side), and the elephants (in the south-east corner). Then the landmarks in the center of the area were presented, i.e. the playground (on the west side), the fountain (in the center), and the ice-cream parlor (on the east side). Lastly, the description continued to present the landmarks on the northern side, i.e. the chimpanzees (in the north-west corner), the lions (in the center of the northern side), and the dolphins (in the north-east corner).

Pointing task

This task consisted of imagining standing in a given position at the Zoo, facing one landmark and pointing to another, and the item to point at was written at the top of the page (e.g. “Imagine being at the entrance, facing the playground and pointing at the fountain”). Under the sentence, there was a circle with an arrow pointing upwards from its center. The center of the circle represented the place where participants imagined standing (the entrance), the tip of the arrow the place they were facing (the playground), and the task involved indicating the direction of a third (target) landmark (e.g. the fountain) by drawing an arrow pointing outwards from the center of the circle in the direction of the target landmark.

Fifty-two pointing tasks were prepared to test imaginary positions, half (26) of which faced north, while the other half (26) faced in the opposite direction (south). There

Fig. 1 Experiment 1. Location of the nine landmarks at the zoo. The *arrows* indicate the path described from the route perspective (Leg 1: entrance–playground–chimpanzees; Leg 2: lions–fountain–ticket booth; Leg 3: elephants–ice-cream parlor–dolphins)



were 14 items on lateral legs and 12 on the central leg facing north (e.g. “Imagine being at the entrance, facing the playground and pointing at the fountain”). The same distinction was used for the tasks that involved pointing south (e.g. “Imagine standing at the playground, facing the entrance and pointing to the fountain”). The pointing headings for each position could be 0° , 45° , 90° , and 180° .

Procedure

Participants were tested individually for about 2 h. They were randomly assigned to route or survey descriptions. They were asked to memorize a description and then perform the recall tasks. They listened to the description twice (an MP3 recording lasting 6 min), then they performed the pointing task; participants read each sentence, then indicated the direction of the landmark by drawing an arrow from the center of the circle outwards. The pointing items were presented in random order. Then they drew a map to reproduce the area and the location of the landmarks. Finally, they were administered the visuospatial tasks (MRT, OPT, SIT and Corsi Blocks task, SDSR scale) and verbal tasks (RCT, Digit Span task) in random order.

Results

Scoring

For the MRT, SIT, and RCT, one point was awarded for each correct answer (two figures identified correctly in the MRT, the right direction in the SIT, the right choice in the RCT). For the WM tasks, the final score corresponded to the length of the longest correctly reproduced sequences. For the OPT and the pointing task, we calculated the absolute angular errors from the differences between the participants’ answers and the right direction.

Two independent judges scored the maps that participants drew, awarding one mark for each correctly-positioned landmark (the two judges’ scores correlated closely, $r = .96$, $p \leq .001$).

Orientation effect

Map drawing task

The mean score was $M = 8.24$ (SD 2.90) and did not differ between the survey and route descriptions ($p > .10$). The

Table 1 Descriptive statistics (means with standard deviations in brackets) for pointing headings facing north and south in Experiments 1 and 2

Pointing heading condition	Descriptions	Experiment 1	Experiment 2
Pointing while facing north	Survey	20.57 (19.65)	
	Route	26.54 (20.65)	
	Total	23.56 (20.17)	34.15 (27.90)
Pointing while facing south	Survey	37.37 (34.95)	
	Route	37.54 (32.71)	
	Total	37.45 (33.49)	43.53 (30.27)
Pointing while facing east	Route		13.61 (6.31)
Pointing while facing west	Route		20.25 (10.41)

For Experiment 1, pointing accuracy is also distinguished by spatial perspective (survey vs route). For Experiment 2, pointing accuracy is also shown for facing west and east

map was north-oriented (i.e. with the landmarks arranged as in Fig. 1) in 46/48 cases, while 2 participants who heard the route text drew the path without placing the landmarks in a layout (they were nonetheless included in the analyses because their pointing performance was within one standard deviation of the whole sample). Overall, this result showed that most of the landmarks were graphically reproduced with a north-up orientation.

Pointing task

A mixed ANOVA 2 (learning perspective: survey vs route) × 2 (gender¹: males vs females)—as between-participants factors—× 2 (pointing heading: facing north vs south)—as a within-participant factor—was conducted (on degrees of error).² The results showed the main effect of pointing heading, $F(1,44) = 22.52, p \leq .001, \eta_p^2 = .34$, where participants’ pointing error was smaller when facing north than when facing south (see descriptive statistics in Table 1). The main effect of gender was also significant,

¹ Males are more accurate in pointing tasks than females (as shown by previous studies; Fields & Shelton, 2006; Pazzaglia & De Beni, 2006), so gender was considered as a factor in the analysis of variance and regression models.

² In a preliminary analysis for Experiment 1, the Leg factor (Leg 1 vs. 2 vs. 3) was included in the ANOVA to check for any differences in pointing performance as a function of the leg involved; no significant effects were found, so this factor was not included in the final analyses.

Table 2 Experiment 1: correlations of visuospatial and verbal measures with pointing headings while facing north and south (degrees of error) in survey and route descriptions

Pointing heading	Route description		Survey description	
	Facing North	Facing South	Facing North	Facing South
Visuospatial measures				
MRT	-.64**	-.53**	-.41*	-.60**
OPT	.70**	.70**	.25	.69**
SIT	-.18	-.17	-.39*	-.51*
Forward Corsi blocks task	-.25	-.23	-.15	-.02
Backward Corsi blocks task	-.30	-.33	-.22	-.11
SDSR scale				
General sense of direction	-.45**	-.46**	-.46*	-.64**
Knowledge and use of cardinal points	-.40**	-.33	-.42*	-.62**
Survey representation	-.29	-.25	-.43*	-.37°
Route representation	-.18	-.17	-.19	-.20
Landmark-centered representation	-.27	-.22	-.10	-.16
Verbal measures				
RCT	-.25	-.29	-.07	-.16
Forward digit span	-.10	-.10	-.02	-.02
Backward digit span	-.19	-.14	-.29	-.13

MRT mental rotations task, OPT object perspective task, SIT spatial indication task, RCT reading comprehension task, SDSR sense of direction and spatial representation

* $p \leq .05$, ** $p \leq .05$, ° $p = .07$

$F(1,44) = 6.57, p = .02, \eta_p^2 = .13$, where males ($M = 20.92, SD 22.14$) performed better than females ($M = 39.17, SD 28.13$). No other significant main effects or interactions emerged ($F < 1$ to $F = 2.68, p = .09$).

Orientation effect, learning perspective and visuospatial abilities

First correlations and then regression models were used to analyze the relationships between visuospatial skills and the recall of spatial descriptions, and how the involvement of visuospatial abilities changed as a function of learning perspective (survey vs route) or the imaginary position adopted (tested with the pointing task facing north vs south).

Correlations

Pearson’s correlations were calculated between visuospatial (MRT, OPT, SIT, Corsi Blocks task, spatial self-

assessments) and verbal measures (RCT and Digit Span tasks) with pointing north and south, distinguishing between survey and route descriptions. As shown in Table 2, only MRT, OPT, SIT, and self-assessments (on general sense of direction and knowledge and use of cardinal points) correlated with north- and south-oriented pointing, with some differences between survey and route descriptions.

Hierarchical regression models

These models were used to clarify the involvement of visuospatial abilities and how their involvement changed as a function of learning perspective and the imaginary position adopted (pointing while facing north or south).

Three steps were implemented and, for each one, the degrees of error were considered as the dependent measure. In the first step, gender, spatial perspective and pointing heading (as dummy variables, see Table 3) were input as predictors, and OPT, MRT and sense of direction as continuous variables (having selected the latter using stepwise regressions³). In the second step, 2-way interactions were input, involving spatial perspective \times pointing heading, spatial perspective \times each spatial measure, and pointing heading \times each spatial measure. In the third step, 3-way interactions involving the spatial perspective, pointing heading and spatial measures were input. The results showed a significant effect of the first ($F = (6, 95) = 14.78, p \leq .001$) and second steps ($F = (5, 95) = 3.09, p \leq .01$), but not of the third ($F < 1$), which respectively accounted for 50, 11 and 1 % of the variance, for a total 62 % of variance.

In particular (see Table 3), the pointing heading factor was significant in the first step ($\beta = .25, p \leq .01$), confirming a different performance in south- and north-oriented pointing (and indicating a better pointing performance while facing north); the MRT ($\beta = -.31, p \leq .01$), OPT ($\beta = .29, p \leq .01$) and sense of direction ($\beta = -.26, p \leq .01$) variables were also significant, showing that higher values for MRT and sense of direction, and lesser degrees of error in the OPT were associated with a better pointing performance. In the second step, the interactions for pointing heading \times OPT ($\beta = .35,$

Table 3 Experiment 1: hierarchical multiple regression on pointing performance (degrees of error)

Predictors	ΔR^2	β^a	t	p
Step 1				
Pointing heading ^b		.25	3.28	.001
Spatial perspective ^c		-.08	-.93	.35
MRT		-.31	-3.10	.003
OPT		.29	3.17	.002
Sense of direction		-.26	-3.11	.002
	.50 ($p \leq .001$)			
Step 2				
Pointing heading \times spatial perspective		.12	.92	.35
Pointing heading \times MRT		-.03	-.27	.78
Pointing heading \times OPT		.35	3.54	.001
Pointing heading \times sense of direction		-.09	-.88	.38
Spatial perspective \times MRT		-.17	-1.54	.13
Spatial perspective \times OPT		-.31	-2.34	.022
Spatial perspective \times sense of direction		-.10	-.85	.39
	.11 ($p \leq .001$)			
Step 3				
3-way interactions		.01 (ns)		
Total	.62			

Significant results are given in boldface

OPT object perspective task, MRT mental rotations test, Sense of direction factor in the SDSR

^a Standardized coefficients

^b Pointing heading: 1 = pointing while facing north, 0 = pointing while facing south

^c Spatial perspective: 1 = survey, 0 = route

$p \leq .01$) and for spatial perspective \times OPT ($\beta = -.31, p = .02$) were significant: the first interaction showed that south-oriented pointing was more strongly associated with OPT performance than north-oriented pointing; the second showed that pointing was more strongly associated with OPT performance in route descriptions than in survey descriptions.

Discussion of the results

Experiment 1 aimed first to explore the orientation effect in mental representations drawn from survey and route descriptions, and second the contribution of visuospatial abilities to said representations and how their role changes as a function of learning perspective and pointing heading, i.e. facing north or south.

³ Experiment 1. Two separate stepwise regression models were run on pointing while facing north and south for all visuospatial measures; both models were significant [$F(2, 45) = 12.04, p \leq .001$ and $F(3, 47) = 21.09, p \leq .001$, respectively], explaining 35 % and 59 % of the variance, respectively. In the first stepwise regression (pointing while facing north), the variables entered were MRT ($\beta = -.40, t = -3.28, p \leq .01$) and sense of direction ($\beta = -.36, t = -2.95, p \leq .01$); in the second stepwise regression (pointing while facing south), the variables entered were OPT ($\beta = .43, t = 3.65, p \leq .001$), sense of direction ($\beta = -.28, t = -2.68, p \leq .01$) and MRT ($\beta = -.29, t = -2.63, p \leq .01$).

Concerning the orientation effect (first aim), our results showed that, after hearing the zoo described from a route or survey perspective, when the initial orientation coincided with the main direction of the information presented (i.e. with a north-up orientation, as shown in Fig. 1), participants performed better in pointing tasks when facing north than when facing south, with no differences between the survey and route perspectives. The preference for organizing information with a north-up orientation was also apparent from performance in the map drawing task, since most of the maps were drawn with this north-up orientation, and with the entrance to the zoo in the bottom left-hand corner.

On the whole, our findings concerning the orientation effect indicate that spatial information verbally conveyed by route and survey descriptions is organized in memory with a specific north-up orientation—as found by Shelton & McNamara, 2004 but we expand on their results by using a pointing task-. These results are not enough, however, for us to be able to conclude definitively that mental representations are north-up oriented because the main modality for delivering the information and the initial orientation were both north-up oriented and, combined with the traditional assumption that north is up, this may confuse the issue. In other words, the north-up orientation effect emerging from the results of our Experiment 1 cannot be clearly attributed to the initial (north-up) heading because this matches with the orientation of the main direction of travel proposed in the description, and coincides with the conventional way of presenting visual input (as on a map with the north uppermost). Hence the question that was approached in our Experiment 2.

As for the involvement of visuospatial abilities (the second aim of Experiment 1), correlation analyses showed that MR and PT abilities (measured with the MRT, OPT and SIT), and self-reported sense of direction and knowledge and use of cardinal points were significantly related to northward and southward pointing performance after learning spatial descriptions from both perspectives. Our hierarchical regression models nonetheless showed that the role of visuospatial skills changes as a function of learning perspective (survey vs route) and of the imaginary positions adopted in the pointing task (facing north vs south). The regression models showed that MR and sense of direction were associated with general pointing performance, and this was also true of PT, but the role of PT also changed depending on the spatial perspective and pointing heading. In fact, the OPT x pointing heading interaction showed that PT performance was strongly associated with pointing while facing south instead of north (i.e. pointing counter-aligned with the main direction of travel expressed in the description). At the same time, the OPT x spatial perspective interaction showed that PT performance was

associated more with pointing performance after hearing descriptions from a route than from a survey perspective.

Taken together, these findings concerning visuospatial abilities showed that, although the ANOVA and regression model revealed no differences in pointing performance after hearing route vs survey descriptions, a difference did emerge when individual spatial measures were analyzed. PT ability (consisting in the ability to imagine adopting misaligned positions in relation to an object layout) became essential to learning route descriptions (when different imaginary positions were tested), which inherently involve a change of orientation when participants imagine moving along a path. So, PT ability is particularly important to support the organization of mental representations when participants have learnt a description from different perspective and have to imagine adopting a position counter-aligned (i.e. facing south) with the orientation used to present the information (mainly facing north), and also when they learn a route description.

To sum up, the results of Experiment 1 indicate that:

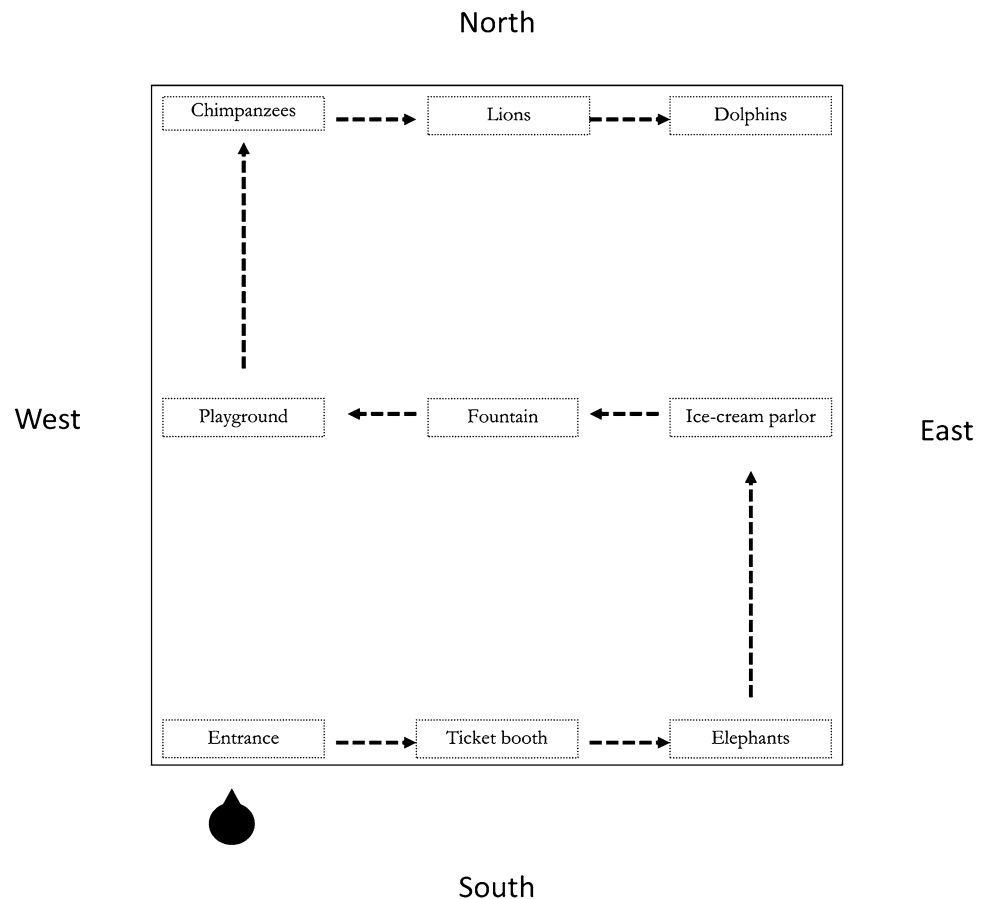
- The orientation effect is detectable when spatial information is learnt from either a survey or a route perspective;
- Visuospatial abilities, and PT skill in particular, are more involved in the maintenance and manipulation of mental representation, when counter-aligned imaginary orientations (e.g. facing south) are involved.

These results needed to be checked, however, by analyzing what happens to the mental representation when the initial imaginary heading is mismatched with the main imaginary direction in which the information is presented, and also the different role of visuospatial abilities in supporting the resulting representation. These questions were newly tested in Experiment 2, in which our first aim was to analyze the orientation of the final mental representations, distinguishing the role of the orientation of the initial heading (as postulated in previous studies by Shelton & McNamara, 2004; Wilson et al., 1999) from that of the main direction of an imaginary tour; as a second aim, we also explored whether visuospatial abilities (and PT in particular) support these mental representations, and how their role changes as a function of the imaginary heading adopted.

Experiment 2

The experimental manipulation used to distinguish the role of initial orientation from that of the primary direction of travel consisted in creating a spatial description and asking listeners to imagine starting in one position (initial heading) and completing an imaginary tour that mainly

Fig. 2 Experiment 2. Location of the nine landmarks at the zoo. The *dotted arrows* show the path described from the route perspective (to distinguish them from those in Experiment 1, these legs were numbered as: Leg 4: entrance–ticket booth–elephants; Leg 5: ice-cream parlor–fountain–playground; Leg 6: chimpanzees–lions–dolphins)



followed another direction (the main direction of travel). The route perspective is a good choice for this type of manipulation so, in Experiment 2, participants listened to a description of the Zoo from a route perspective: the path started at the entrance gate (north-up oriented, as in Experiment 1), then they had to imagine turning right, and moving along a path from west to east and vice versa (see Fig. 2). Orientation dependence was tested with a pointing task asking participants to indicate imaginary positions while facing north and south (as in Experiment 1), and west and east. The map drawing task was also included.

As concerns the orientation effect (our first aim), the two types of outcome expected were:

- If the initial viewpoint has a prominent role in influencing the representation stored in memory, we would expect much the same pattern of pointing performance in Experiment 2 as in Experiment 1 (i.e. a better pointing performance while facing north than while facing south) because the initial orientation was north-up (as seen in previous studies, e.g. Fields & Shelton, 2006; Shelton & McNamara, 2004);

- If the main direction taken along the path has a prominent role, then we would expect to see a difference in pointing performance between Experiments 1 and 2, and pointing east–west (which was the main direction of the imaginary viewpoint experienced in the description of the path) should be better than north–south pointing in Experiment 2.

As for the influence of visuospatial abilities (our second aim), we tested how these skills affect mental representations (as shown in Experiment 1) and, in particular, whether PT ability supports the maintenance and manipulation of mentally represented information, with a role that can differ as a function of the imaginary headings tested with the pointing task (facing north vs south; facing east vs west).

Method

Participants

The study involved 40 university students (20 males; mean age 21.57 years).

Material

The same visuospatial and verbal measures were used as in Experiment 1.

Route description

A new version of the path through the Zoo was prepared from a route perspective (275 words), using the same landmark locations in the Zoo's layout as in Experiment 1 (see Fig. 2). The new path was divided into three legs: it started at the entrance gate in the bottom left-hand corner, as in Experiment 1 (a pilot study had demonstrated that participants identified the starting point as in Fig. 1), but then the path turned 90° to the right, towards the ticket booth and then in the direction of the elephants (with information oriented eastwards; this was called Leg 4 to distinguish it from the first three legs considered in Experiment 1). Then the path changed direction again, turning through 90° to head from the ice-cream parlor towards the fountain, and on to the playground (Leg 5, with information oriented westwards), and then it turned twice through 90° again to go from the chimpanzees towards the lions and dolphins (Leg 6, with information oriented eastwards again).

Pointing task

A total of 104 pointing items were used, distinguishing between pointing while facing north vs south, and east vs west: 52 items (26 facing north, and 26 facing south) were the same as those used in Experiment 1; the other 52 items were west- or east-facing (26 each). There were 14 items along the lateral legs and 12 along the central leg in the eastward direction (e.g. "Imagine being at the ticket booth, facing the elephants and pointing to the fountain", Fig. 2), and the same number of items for the westward direction (e.g. "Imagine being at the elephants, facing the ticket booth and pointing to the fountain", Fig. 2). The pointing headings could be at 0°, 45°, 90°, and 180°.

Procedure

Participants were tested individually for a total of two and a half hours. First they listened to the route description twice (an MP3 recording lasting 6 min). Then they completed the 104 pointing items (presented in random order using the same method as in Experiment 1) and they performed the map drawing task. Participants then performed the visuospatial (MRT, OPT, SIT and Corsi Blocks task) and verbal tasks (RCT, Digit Span task) in random order.

Results

Scoring

This was the same as in Experiment 1 for the visuospatial and verbal tasks, and map drawing (for which the two judges' scores correlated closely [$r = .96$ $p \leq .001$]).

Orientation effect

Map drawing task

Two participants failed to locate any of the landmarks correctly and were omitted from the analyses. The remaining 38 participants' mean score for map drawing was $M = 7.71$ (SD 3.06). Thirty-five of these 38 participants arranged the landmarks with a north-up orientation, while 3 depicted the path without locating it within a layout (they were included in the analyses because their performance was within one standard deviation of the sample as a whole). These results showed that mental representations organized in a north-up orientation are attributable to the initial heading orientation presented, or the canonical north-up orientation.

Pointing task

Preliminary analyses were conducted on pointing while facing north and south on segments included respectively in Legs 1, 2, 3 (those proposed in Experiment 1) in order to compare participants' performance with imaginary positions experienced along the path (such as the playground to chimpanzees segment) or not experienced (such as the entrance to playground segment). The comparison of pointing while facing north showed no difference in performance between single segments, and no difference for experienced vs non-experienced segments ($F < 1$ to $F = 1.53$, $p = .22$). There were also no differences in pointing performance for the single segments while facing south ($F_s < 1$). For control purposes, pointing performance comparisons were also drawn for single segments facing east and west. The results obtained while facing east showed that performance for pointing at imaginary positions referring to the "entrance gate to ticket booth" segment of Leg 4 generated higher degrees of error ($M = 90.11$, SD 31.74) than for the other "ticket booth to elephants" segment of Leg 4 ($M = 33.86$, SD = 30.95), or the mean for the other pointing items (more than 3 SD of the sum of the degrees of error for the other items). No significant differences were found ($F_s < 1$) for the other segments, or for the segments that involved pointing while facing west ($F < 1$ to $F = 2.14$, $p = .15$). In the final

analysis, we considered only pointing while facing east for the “ticket booth to elephants” leg, which was renamed Leg 4-revised.

Repeated-measures ANOVA⁴ (pointing heading: north vs south vs west vs east) \times 2 (gender: males vs females) only showed the main effect of pointing heading, $F(3,114) = 25.81, p \leq .001, \eta_p^2 = .41$. Post hoc comparisons showed that all means differed from the others ($p_s < .01$): pointing while facing east ($M = 13.61, SD 6.31$) showed fewer degrees of error than pointing while facing west ($M = 20.25, SD 10.41$, see also Table 1), while facing north ($M = 34.15, SD 27.90$), or while facing south ($M = 43.53, SD 30.27$). Pointing was easier while facing west than while facing north or south. As in Experiment 1, however, pointing while facing north was easier than pointing while facing south. No other significant main effects or interactions were found ($F < 1$ to $F = 1.75, p = .18$).

Orientation effect and visuospatial abilities

Pearson’s correlations were calculated between visuospatial and verbal measures with pointing while facing north and south (as in Experiment 1), and west and east. As shown in Table 4, pointing while facing north and south correlated significantly with MRT, OPT, SIT, and with self-assessments on general sense of direction, knowledge and use of cardinal points (as in Experiment 1), and survey and route representations. As for pointing while facing east and west, only pointing while facing west correlated significantly with MRT, OPT and SIT measures (but not with spatial self-assessments), and pointing while facing east did not correlate with any of the measures.

Two hierarchical regression models were implemented to clarify the role of visuospatial abilities in supporting pointing accuracy from differently-oriented imaginary positions (the degrees of error in pointing while facing north–south, and in pointing while facing east–west were the dependent variables in the first and second regression models, respectively).

⁴ Experiment 2. The final 4×2 analysis of variance was based on the degrees of error without the segment going from the entrance to the ticket booth in Leg 4. When the same analysis was run including both the segments of Leg 4, the results showed the main effect of orientation $F(3, 114) = 10.63, p \leq .01, \eta_p^2 = .28$; post hoc comparisons confirmed that pointing while facing north ($M = 32.63, SD 28.34$) was easier than pointing while facing south ($M = 41.68, SD 34.11$) (as reported in the manuscript); on the other hand, pointing while facing east ($M = 52.34, SD 17.45$) coincided with a worse performance than pointing while facing west ($M = 27.15, SD 23.20, p < .01$) or north ($p = .01$) due to the greater error for the segment going from the entrance to the ticket booth.

Table 4 Experiment 2: correlations of visuospatial and verbal measures with pointing heading while facing north, south, east and west (degrees of error) after hearing route descriptions

Pointing heading	Route description			
	Facing North	Facing South	Facing East	Facing West
Visuospatial measures				
MRT	-.53**	-.52**	-.23	-.43**
OPT	.54**	.57**	.05	.51**
SIT	-.52**	-.53**	-.05	-.36*
Forward Corsi blocks task	-.24	-.24	-.10	-.25
Backward Corsi blocks task	-.28	-.29	-.23	-.28
SDSR scale				
General sense of direction	-.30°	-.35*	-.12	-.22
Knowledge and use of cardinal points	-.37*	-.44**	.05	-.23
Survey representation	-.32*	-.33*	-.10	-.26
Route representation	-.30°	-.32*	.09	-.12
Landmark-centered representation	-.15	-.13	-.05	-.11
Verbal measures				
RCT	-.15	-.09	-.11	-.13
Forward digit span	-.18	-.19	-.08	-.08
Backward digit span	-.04	-.11	-.26	-.05

MRT mental rotations task, OPT object perspective task, SIT spatial indication task, RCT reading comprehension task, SDSR sense of direction and spatial representation

* $p \leq .05$, ** $p \leq .05$, ° $p = .07$

In the first regression model (analyzing pointing while facing north–south), gender and pointing heading as dummy variables (see Table 5), and OPT, SIT (as visuospatial measures selected on the strength of stepwise regressions⁵) as continuous variables were input as independent factors in the first step. The 2-way interactions, pointing heading \times OPT, and pointing heading \times SIT, were input in the second step. The results showed a

⁵ Experiment 2. Two separate stepwise regression models were run on pointing while facing north and south for all visuospatial measures, and both models were significant [$F(2, 39) = 12.53, p \leq .001$ and $F(2, 39) = 14.11, p \leq .001$, respectively], explaining 40 and 43 % of the variance, respectively. In both models, the variables entered were the OPT [pointing while facing north: ($\beta = .40$), $t = 2.89, p \leq .01$; pointing while facing south: ($\beta = .42$), $t = 3.16, p \leq .01$], and the SIT [pointing while facing north: ($\beta = -.37$), $t = -2.66, p = .01$; pointing while facing south: ($\beta = -.37$), $t = -2.72, p = .01$]. The two stepwise regression models run on pointing while facing east and west generated significant results only for pointing while facing west, $F(1, 39) = 13.05, p \leq .01$, explaining 27 % of the variance; the only variable entered in the model was the OPT [($\beta = .51$), $t = 3.61, p \leq .001$].

Table 5 Experiment 2: hierarchical multiple regression on north-south and east-west pointing performance (degrees of error)

Predictors	ΔR^2	β^a	<i>t</i>	<i>p</i>
North-south pointing model				
Step 1				
Pointing heading ^b	.45 (<i>p</i> ≤ .01)	.15	1.74	.07
OPT		.41	4.39	.001
SIT		−.38	−3.39	.01
Gender		−.11	−1.19	.24
Step 2				
2-way interactions	.01 (ns)			
Total	46 %			
East-west pointing model				
Step 1				
Pointing heading ^{b,c}	.23 (<i>p</i> ≤ .001)	.36	3.61	.01
OPT		.31	3.07	.01
Gender		−.07	−.74	.46
Step 2				
Pointing heading ^b × OPT	.10 (<i>p</i> ≤ .01)	.38	2.78	.01
Total	33 %			

Significant results are given in boldface

OPT object perspective task, SIT spatial indication task

^a Standardized coefficients

^b Pointing heading: 1 = pointing while facing north, 0 = pointing while facing south

^c Pointing heading: 1 = pointing while facing east, 0 = pointing while facing west

significant effect of the first step ($F = (4, 79) = 14.67$, $p \leq .001$), but not of the second ($F < 1$), accounting for 45 and 1 % of the variance, respectively (for a total of 46 % of the variance). In particular, pointing heading tended to be significant in the first step ($\beta = .15$, $p = .07$), where pointing performance while facing south and north tended to differ (and be better for the latter); the effects of OPT ($\beta = .41$, $p \leq .001$) and SIT ($\beta = -.38$, $p \leq .01$) were significant, showing that lower OPT values (smaller degrees of error) and higher scores (accuracy) for SIT were associated with smaller pointing errors. No interactions with pointing heading emerged (see Table 5 for details).

In the second regression model (analyzing pointing while facing east-west), gender and pointing heading as dummy variables (see Table 5), and OPT (the visuospatial measure chosen with the previous stepwise regression) as a continuous variable were input as independent factors in the first step. The 2-way pointing heading × OPT interaction was added in the second step. The results showed a significant effect of the first step, $F = (3, 79) = 7.51$, $p \leq .001$, and of the second step, $F = (4, 79) = 8.06$,

$p \leq .001$, accounting for 23 and 10 % of the variance, respectively (for a total of 33 % of the variance). The effect of pointing heading was significant in the first step ($\beta = .36$, $p \leq .01$), showing that pointing performance while facing west and east differed (it was better while facing east). There was also a significant effect of OPT ($\beta = .31$, $p \leq .01$), showing that fewer degrees of error in the OPT were associated with fewer degrees of error in pointing while facing east or west; the significant interaction found in the second step for pointing heading × OPT ($\beta = .38$, $p \leq .01$) indicated that pointing while facing west (i.e. mainly counter-aligned with the direction of travel) was more strongly associated with OPT performance than pointing while facing east (see Table 5 for details).

Discussion of results

The first aim of Experiment 2 was to shed light on whether the orientation effect is more influenced by the initial orientation (north-up oriented) or by the primary direction of travel (mainly east-west oriented); as a second aim, this orientation effect was explored in relation to the involvement of visuospatial abilities.

Regarding the first aim, our results showed that pointing while facing north was easier than pointing while facing south, and that map drawings were mainly organized with a north-up orientation (as showed in Experiment 1). Although these findings indicated that mental representations were organized with a north-up orientation, assessing pointing oriented eastwards and westwards provided further information on the development of mental representations based on other orientations. Our results of Experiment 2 showed that pointing while facing east (i.e. consistently with the main direction of the imaginary tour) was easier than pointing while facing west, south or north indicating that participants benefited from pointing in the main direction of travel (i.e. with an eastward orientation in our case). These results demonstrate that the main direction of travel was memorized; at the same time, the initially imagined heading (north-up oriented) still facilitated the organization of the mental representation.

It is worth mentioning that the change of heading at the beginning of the path (“at the entrance gate turn right immediately”) was associated with the worst pointing performance (three times the overall pointing error): the initial north-up orientation (that provides the basis for orienting the mental representation) was strongly affected by the right turn introducing another orientation, which seems to interrupt the spontaneous development of the

mental representation, i.e. the preference for aligning information from south to north. The description went on to cover an imaginary tour mainly from east to west and participants also encoded this orientation, which was included in the final mental representation.

On the whole, our findings concerning the orientation effect indicate that the main direction of travel is memorized despite a preference for the north-up orientation. The finding that mental representations store different orientations in the memory seems particularly interesting when analyzed in relation to the visuospatial abilities involved (i.e. our second aim). Pointing efficiency while facing north and south correlated significantly with performance in the visuospatial tasks (MRT, SIT, OPT) and with self-assessments on sense of direction and spatial representation preferences. Pointing while facing west also correlated significantly with performance in visuospatial tasks (MRT, SIT, OPT), but not with self-assessments; on the other hand, pointing while facing east showed no significant correlation with any of the visuospatial or verbal measures considered. These results indicate that visuospatial abilities were involved mainly in pointing tasks misaligned with the imaginary direction of travel proposed in the description; indeed, performance in pointing eastwards (expressing the main direction of the travel) did not correlate with the visuospatial measures. This different contribution of visuospatial abilities depending on the imaginary orientation being tested with the pointing task becomes more clear from the results of the regression models. Pointing while facing south or north was supported exclusively by PT ability (measured with the OPT and SIT). Pointing while facing east or west involved PT skills too, but the pointing heading \times OPT interaction showed that pointing while facing west (i.e. counter-aligned with the main direction of travel) was more strongly associated with PT ability than pointing while facing east (i.e. mainly aligned with the main direction of travel).

To sum up, the results of Experiment 2 indicate that:

- The mental representation of the description of a path was oriented according to the main direction of the imaginary travel, even though the influence of the initial heading persisted;
- Visuospatial skills, and PT ability especially, are mainly involved in maintaining and manipulating mental representations, i.e. when imaginary pointing headings are counter-aligned or misaligned vis-à-vis the main direction of travel.

Conclusions

The present study was conducted to clarify the factors influencing the orientation effect of mental representations

derived from spatial descriptions. As external factors, we analyzed the role of the perspective used to describe an environment (classically distinguishing between survey and route perspectives, in Experiment 1), and the orientation in which the information is presented in descriptions, given by the initial heading and the main direction of travel being described (Experiment 2). The impact of these aspects on mental representations was analyzed in relation to individual factors such as visuospatial abilities, i.e. how the role of these abilities changes as a function of the perspective and the orientation in which information is presented (initial orientation vs main direction of travel), in both Experiments 1 and 2. Spatial recall of the environment described was tested by asking participants to adopt imaginary heading positions, i.e. to perform pointing task while facing north vs south (in both Experiments), or while facing east vs west (in Experiment 2), and by administering map drawing task.

The theoretical premises supporting these experiments are:

- Previous studies had indicated that mental representations derived from spatial descriptions are organized in memory with a certain orientation, believed to depend on the initial imaginary orientation of the description (Shelton & McNamara, 2004, Wilson et al., 1999; Wildbur & Wilson, 2008). To our knowledge, however, only Shelton & McNamara (2004) examined survey and route descriptions of outdoor environments (adapting the typical descriptions used by Taylor & Tversky, 1992), instead of using fictitious U-shaped paths (like Wilson et al., 1999). While the type of description used by Shelton & McNamara (2004) is convincing (they described a complete outdoor environment), they tested the orientation of the representation with a visual test, not the pointing task (the latter is a more representative measure of spatial memory organization). In previous studies, moreover (e.g. Shelton & McNamara, 2004; Wilson & Wilbur, 2004), the initial heading in which information was presented coincided with the main direction of travel (which were both mainly north-up oriented). On the whole, previous findings indicated that mental representations derived from spatial descriptions are orientation-dependent, but this result needs to be further developed by analyzing the role of learning perspective and the orientation adopted with respect to the initial orientation and main direction of travel. Thus, our first aim was to test the orientation effect in relation to the spatial perspective used to convey spatial descriptions (in Experiment 1), and in relation to the initial orientation vs the main direction of travel (in Experiment 2, focusing on a route description).

- Visuospatial abilities have a central role in environmental learning (e.g. Allen et al., 1996), even when information is conveyed verbally (e.g. Bosco, Filomena, Sardone, Scalisi, & Longoni, 1996; Pazzaglia, 2008; Meneghetti et al., 2009). But no studies have used spatial descriptions to explore the influence of individual differences in visuospatial skills on the orientation effect, taking at the same time the learning perspective and the imaginary orientation adopted in the learning phase into account. So, our second aim was to test the influence of visuospatial abilities on the ability to maintain and manipulate the orientation of mental representations obtained from survey and route descriptions (in Experiment 1), and when the description consisted of a route description in which initial orientation and main direction of travel were dissociated (in Experiment 2).

Based on these premises, we conducted two experiments to analyze the orientation effect (our first aim), and the role of visuospatial abilities (our second aim) in mental representations derived from spatial descriptions. In Experiment 1, participants listened to the description of a zoo from a survey or route perspective in which the information was presented mainly oriented northwards (see Fig. 1), then they performed pointing tasks that tested imaginary headings mainly aligned or counter-aligned with the listeners' imaginary point of view (i.e. while facing north or south); they also completed map drawing tasks.

Concerning our first aim, the results of Experiment 1 showed that mental representations were preferably organized with a north-up orientation. When the information presented was oriented mainly north-up (in terms of both the initial orientation and the imaginary tour), pointing while facing north was easier than while facing south, irrespective of whether the spatial environment information was provided from a route or a survey perspective. This goes to show that the mental representation is clearly organized in a north-up sense whatever the learning perspective adopted. Overall, the results of Experiment 1 confirmed that mental representations derived from spatial descriptions acquired from a route or survey perspective and tested using imaginary headings in the same or opposite direction to the one in which the information was mainly presented (i.e. north up), were represented mentally with a north-up orientation. These results are in line with previous findings (Shelton & McNamara, 2004; Wilson et al., 1999), despite having made changes to the experimental material, such as realistic environment descriptions instead of only U-shaped configurations (as in Wilson et al., 1999; Wildbur & Wilson, 2008), and the use of pointing tasks the test recall instead of scene recognition tasks (as in Shelton & McNamara, 2004, Exp. 1).

Experiment 2, on the other hand, newly showed that this preference for a north-up orientation is attenuated when other imaginary orientations are experienced. In Experiment 2, participants listened to the description of a path through the zoo from a route perspective in which the initial orientation (north-up oriented) was mismatched with the main direction of travel (mainly east–west oriented). Our Experiment 1 and previous studies (Shelton & McNamara, 2004; Fields & Shelton, 2006) had collapsed these two variables together, keeping the initial imaginary heading and the main direction of travel north-up oriented. In our Experiment 2 we developed a path description in which the initial heading was north-up oriented, but the main direction of travel was east-oriented, thereby considering the orientation of the path covered (not just the initial imaginary heading) as a separate factor influencing the mental representation's features (see Fig. 2). After hearing this modified description, participants performed pointing tasks while facing north, south, east and west.

The results of Experiment 2 showed that pointing while facing east (consistently with the path's main orientation) was easier than pointing while facing west, south or north, meaning that individuals memorize the orientation of their imaginary tour. When we tested imaginary positions facing north and south again, pointing while facing north proved easier than pointing while facing south, indicating that the preference for a north-up orientation persisted even when other orientations were experienced.

The corresponding map drawings were mainly north-up oriented, suggesting that a north-up orientation of the mental representation remained strongly influential, even when participants stored experiences of other (east and west) orientations of imaginary tours in their memory. So direction of travel still has a role in modulating the characteristics of mental representations even when it is not aligned with the initial imaginary view, although the latter continues to influence the mental representation.

Overall, when the initial north-up orientation coincided with the main direction of travel in the description of an environments, presented from either a survey or a route perspective (as in Experiment 1), the information was strongly represented in memory with a specific (north-up) orientation. However, when we tested whether the orientation effect was due to the initial orientation of the information or to the main direction of travel (in Experiment 2), the mental representation incorporated the main orientation experienced in the imaginary tour, even though there was still evidence of a preference for a north-up orientation. In other words, mental representations derived from spatial descriptions proved to be orientation-dependent, but the initial imaginary heading was not the only factor involved in determining the mental representation's organization (as postulated by Shelton & McNamara, 2004; Wilson et al., 1999; Fields & Shelton, 2006); the main

direction of travel strongly influenced the representation too. Thus, when more imaginary orientations were experienced, the mental representation became less susceptible to the orientation effect induced by the initial view. The fact that multiple views could be incorporated in the mental representations may be specifically attributable to the use of a route perspective. In fact, a flexible mental representation could be formed after hearing or reading a route description (Brunyé & Taylor, 2008; Meneghetti, Pazzaglia et al., 2011), especially when the initial orientation is presented in a northwards direction (as opposed to other initial headings experienced, as recently found by Gagnon et al., 2013). Our results seem interesting, but further studies are needed because our study provides the first evidence of other orientations (in addition to the one initially encoded) being stored in memory (also in Gagnon et al., 2013 the initial orientation matched the main direction of travel), and no studies have yet investigated the mismatching of information presented in survey descriptions.

Concerning our second aim, the results showed that individual spatial factors are involved in retaining and manipulating the orientation of mental representations derived from survey and route descriptions. Our findings primarily show the strong involvement of visuospatial abilities, and particularly the fundamental role of PT ability when imaginary positions being tested are not north-up oriented. The OPT (which tests the ability to imagine adopting different orientations in a configuration of objects misaligned with the observer's view) was the best predictor of pointing performance when participants had to adopt imaginary positions counter-aligned with the orientation mainly encoded, i.e. when pointing while facing south after hearing mainly north-oriented descriptions (Experiment 1, for both survey and route perspectives); or when pointing while facing west after hearing mainly east-oriented route descriptions (Experiment 2). In other words, when participants encoded spatial information going mainly from south to north, or from west to east (as in Experiments 1 and 2, respectively), they memorized the information about the given orientation making limited use of their visuospatial skills; but when they had to manipulate their mental representation and imagine being in a position counter-aligned with the mainly-encoded orientation, the burden on their visuospatial abilities increased and their PT skills influenced their performance much more. Our two experiments therefore consistently showed that PT is an individual spatial factor fundamental to supporting imaginary positions counter-aligned with the encoded main direction of imaginary travel.

The results obtained in our Experiment 2 also showed that PT ability influenced performance not only when it came to imagining positions counter-aligned with the main

direction of travel (as mentioned above), but also when other imaginary misaligned positions were tested, such as pointing while facing north–south after hearing descriptions with an east–west orientation. PT was therefore the primary individual spatial ability needed to support counter-aligned and misaligned positions vis-à-vis the main direction of travel.

An additional finding is also worth noting: performance in the OPT interacted with the spatial perspective learnt (as shown in Experiment 1), where PT ability was more strongly associated with pointing performance concerning route descriptions than for survey descriptions. This result is of interest because it corroborates the impressions that the OPT measures the subjective spatial transformation (not the objective spatial transformation measured, for instance, by the MRT; Hegarty & Waller, 2004), an ability that could underpin the subjective changes made to a person's point of view after hearing route descriptions (but not in survey descriptions). This finding needs to be further developed, however, collecting more evidence by exploring the involvement of the different spatial skills—and PT in particular—in relation to the spatial perspective and the orientation effect.

Overall, our findings reinforce the central role of visuospatial abilities in mental representations derived from environment descriptions, as already demonstrated by previous studies (Pazzaglia, 2008; Meneghetti et al., 2009; Meneghetti, De Beni et al., 2011), with the additional novel finding that visuospatial skills, and particularly perspective taking ability (as measured with the OPT), interact with the orientation effect (identified in Experiments 1 and 2) and with the spatial perspective learnt (as seen in by Experiment 1). Indeed, PT ability was the prominent predictor of pointing performance when a route description was learnt (Experiment 1), and when the imaginary positions being tested were counter-aligned (Experiments 1 and 2) or otherwise oriented (Experiment 2) with respect to the main orientation presented in the description. It is worth emphasizing the affinity between the OPT and pointing tasks: the OPT tests people's ability to take an imaginary new perspective within a configuration of objects that are not aligned with their position; the direction is judged while being able to refer to the object configuration. The pointing task involves imagining being in positions counter-aligned with the direction in which the information was expressed, but (unlike the OPT) without being able to see the configuration of objects. Both tasks were designed to measure how people are able to adopt new imaginary positions misaligned with the perceived layout of a configuration (as in the OPT) or with their recall of an environment they have learned (as in the pointing task). PT thus emerged as a sensitive individual spatial ability capable of modulating the orientation adopted in a mental

representation, and involved especially when imaginary orientations have to be counter-aligned or misaligned with the orientation used to encode the information. This is a novel finding for spatial descriptions (expressed from different perspectives and with different imaginary orientations), and wholly consistent with findings based on virtual navigation, i.e. using visual input (Fields & Shelton, 2006).

Taken together, our findings support the conviction that mental representations of environment descriptions have spatial properties that depend on the features of the mental representation itself and on individual visuospatial abilities needed to develop and maintain the mental representation. The spatial property investigated here is orientation-dependent, an effect explored so far using visual inputs and methods and tasks borrowed from the verbal domain. The preference for a north-up orientation of mental representations derived from spatial descriptions (Shelton & McNamara, 2004; Wilson et al., 1999; Wildbur & Wilson, 2008) may have properties similar to those identified using visual input (such as maps and virtual displays—Richardson et al., 1999; Hegarty et al., 2006, or real exploration—Frankenstein, Mohler, Bühlhoff, & Meilinger, 2012; Sluzensky, Meneghetti, & McNamara, 2011), and this supports the similarity of visual and verbal input in producing preferentially north-up oriented mental representations. At the same time, our results newly indicate that mental representations derived from spatial descriptions are complex, and the preference for a north-up orientation can be attenuated when non-canonical distances are covered along an imaginary path. In other words, when participants heard descriptions with different orientations from the one initially learnt, these different orientations were stored in their memory too. At first glance, this might be seen as a peculiar feature due to the use of verbal descriptions. In virtual city navigation, Frankenstein et al. (2012) showed that, although different orientations were experienced, the north-up one was the best represented in people's memory. The fact that other orientations (east–west in our case) used in descriptions are stored in memory too deserves further attention to clarify whether this is due to the verbal description being used (and the route perspective in particular) or to some other experimental condition (e.g. Frankenstein's participants had lived in the city in which they navigated for at least 2 years, whereas in our study the information about the zoo was encoded for the first time). Thus, as mentioned earlier, although on the whole our findings are of interest, further data need to be collected—considering other variables (e.g. other types of input), and manipulating other factors (e.g. other non-canonical orientations along the paths being covered from both survey and route perspectives)—to improve our understanding of orientation dependence in descriptions.

In conclusion, the findings of Experiments 1 and 2 mainly showed that mental representations of environment descriptions:

- Are organized in memory with a preferred orientation regardless of whether the descriptions were given from a survey or from a route perspective; this orientation effect on spatial descriptions was mainly influenced by the main direction of travel, and secondly by the initial orientation presented (for descriptions from a route perspective at least);
- Demand visuospatial abilities, and perspective-taking ones in particular, to retain and manipulate the mental representation's orientation, especially when it becomes necessary to adopt imaginary headings that are counter-aligned with the main orientation expressed in descriptions and encoded from a route perspective.

References

- Allen, G. L., Kirasic, K. C., Dobson, S. H., Long, R. G., & Beck, S. (1996). Predicting environmental learning from spatial abilities: an indirect route. *Intelligence*, 22, 327–355. doi:10.1016/S0160-2896(96)90026-4.
- Baldwin, C. L., & Reagan, I. (2009). Individual differences in route-learning strategy and associated working memory resources. *Human Factors*, 51, 368–377. doi:10.1177/0018720809338187.
- Bosco, A., Filomena, S., Sardone, L., Scalisi, T. G., & Longoni, A. M. (1996). Spatial models derived from verbal descriptions of fictitious environments: the influence of study time and the individual differences in visuo-spatial ability. *Psychologische Beiträge*, 38, 451–464.
- Brunye, T. T., & Taylor, H. A. (2008). 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.
- Cornoldi, C., Rizzo, A., & Pra Baldi, A. (1991). *Prove avanzate MT di comprensione della lettura [Advanced MT reading comprehension task]*. Florence: Organizzazioni Speciali.
- Corsi, P. M. (1972). *Human memory and the medial temporal region of the brain [Doctoral dissertation]*. Montreal: McGill University.
- Fields, A. W., & Shelton, A. L. (2006). Individual skill differences and large-scale environmental learning. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 32, 506–515. doi:10.1037/0278-7393.32.3.506.
- Frankenstein, J., Mohler, B. J., Bühlhoff, H. H., & Meilinger, T. (2012). Is the map in our head oriented north? *Psychological Science*, 23, 120–125. doi:10.1177/0956797611429467.
- Gagnon, S. A., Brunyé, T. T., Gardony, A., Noordzij, M. L., Mahoney, C. R., & Taylor, H. A. (2013). Stepping into a map: initial heading direction influences spatial memory flexibility. *Cognitive Science*,. doi:10.1111/cogs.12055.
- Gyselinck, V., Cornoldi, C., Dubois, V., De Beni, R., & Ehrlich, M. F. (2002). Visuo-spatial memory and phonological loop in learning from multimedia. *Applied Cognitive Psychology*, 16, 665–685. doi:10.1002/acp.823.
- 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 (Eds.), *Spatial Working Memory* (pp. 159–180). Psychology Press, Portfolio.
- Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial ability 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.
- Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, *32*, 175–191. doi:10.1016/j.intell.2003.12.001.
- Johnson-Laird, P. N. (1983). *Mental models: towards a cognitive science of language, inference and consciousness*. Cambridge: Harvard University Press.
- Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object-manipulation spatial ability and spatial orientation ability. *Memory and Cognition*, *29*, 745–756. doi:10.3758/BF03200477.
- Lawton, C. A. (1996). Strategies for indoor wayfinding: the role of orientation. *Journal of Environmental Psychology*, *16*, 137–145. doi:10.1006/jevp.1996.0011.
- Logie, R. H. (1995). *Visuo-spatial working memory*. UK: Lawrence Erlbaum Associates Ltd.
- Meneghetti, C., Gyselinck, V., Pazzaglia, F., & Beni, De. (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., De Beni, R., Gyselinck, V., & Pazzaglia, F. (2011a). 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., Pazzaglia, F., & De Beni, R. (2011b). 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.
- Meneghetti, C., Ronconi, L., Pazzaglia, F., & De Beni, R. (2013). Spatial mental representation derived from spatial descriptions: the predicting and mediating role of spatial preferences, abilities and strategies. *British Journal of Psychology*. doi:10.1111/bjop.12038.
- 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: Lawrence Erlbaum Associates.
- Morrow, D. G., Stine-Morrow, E. A. L., Leirer, V. O., Andrassy, J. M., & Kahn, J. (1997). The role of reader age and focus of attention in creating situation models from narratives. *Journal of Gerontology: Psychological Sciences*, *52*, 73–80. doi:10.1093/geronb/52B.2.P73.
- Nori, R., & Giuseberti, F. (2003). Cognitive styles: errors in directional judgments. *Perception*, *32*, 307–320. doi:10.1068/p3380.
- Pazzaglia, F. (2008). Text and picture integration in comprehending and memorizing spatial descriptions. In J. F. Rouet & R. K. Lowe (Eds.), *Understanding multimedia documents* (pp. 43–59). NYC, US: Springer.
- 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., Cornoldi, C., & De Beni, R. (2000). Differenze individuali nella rappresentazione dello spazio: presentazione di un questionario autovalutativo [Individual differences in representation of space: presentation of a questionnaire]. *Giornale Italiano di Psicologia*, *3*, 627–650. doi:10.1421/310.
- Pazzaglia, F., & De Beni, R. (2001). Strategies of processing spatial information in survey and landmark-centred individuals. *European Journal of Cognitive Psychology*, *13*, 493–508. doi:10.1080/09541440125778.
- Pazzaglia, F., & De Beni, R. (2006). Are people with high and low mental rotation abilities differently susceptible to the alignment effect? *Perception*, *35*, 369–383. doi:10.1068/p5465.
- Pazzaglia, F., Gyselinck, V., Cornoldi, C., & De Beni, R. (2012). Individual differences in spatial text processing. In V. Gyselinck & F. Pazzaglia (Eds.), *From mental imagery to spatial cognition and language: essays in honor of Michel Denis* (pp. 127–161). Hove: Psychology Press.
- Pazzaglia, F., & Meneghetti, C. (2012). Spatial text processing in relation to spatial abilities and spatial styles. *Journal of Cognitive Psychology*, *24*, 972–980. doi:10.1080/20445911.2012.725716.
- 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.
- Presson, C. C., DeLange, N., & Hazelrigg, M. D. (1987). Orientation specificity in kinesthetic spatial learning: the role of multiple orientations. *Memory & Cognition*, *15*, 225–229. doi:10.3758/BF03197720.
- Presson, C. C., DeLange, N., & Hazelrigg, M. D. (1989). Orientation specificity in spatial memory: what makes a path different from a map of the path? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 887–897. doi:10.1037/0278-7393.15.5.887.
- Presson, C. C., & Hazelrigg, M. D. (1984). Building spatial representations through primary and secondary learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 716–722. doi:10.1037/0278-7393.10.4.716.
- Richardson, A. E., Montello, D., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition*, *27*, 741–750. doi:10.3758/BF03211566.
- Rinck, M., Hahnel, A., Bower, G. H., & Glowalla, U. (1997). The metrics of spatial situation models. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*, 506–515. doi:10.1037/0278-7393.23.3.622.
- Shelton, A. L., & Gabrieli, J. D. E. (2004). Neural correlates of individual differences in spatial learning strategies. *Neuropsychology*, *18*, 442–449. doi:10.1037/0894-4105.18.3.442.
- Shelton, A. L., & McNamara, T. P. (2001). Systems of spatial reference in human memory. *Cognitive Psychology*, *43*, 274–310. doi:10.1006/cogp.2001.0758.
- Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*, 158–170. doi:10.1037/0278-7393.30.1.158.
- Sluzenski, J., Meneghetti, C., & McNamara, T. P. (2011). Spatial influence of environmental axes in a baseball field. *Spatial Cognition & Computation*, *11*, 205–225. doi:10.1080/13875868.2010.542262.
- 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.
- Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotation, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, *47*, 599–604. doi:10.2466/pms.1978.47.2.599.
- Wechsler, D. (1981). *Wechsler adult intelligence scale (rev. ed.)*. New York: Psychological Corporation.
- Wildbur, D. J., & Wilson, P. N. (2008). Influences on the first-perspective alignment effect from text route descriptions. *The Quarterly Journal of Experimental Psychology*, *61*, 763–783. doi:10.1080/17470210701303224.
- Wilson, P. N., Tlauka, M., & Wildbur, D. (1999). Orientation specificity occurs in both small- and large-scale imagined routes

- presented as verbal descriptions. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 25, 664–679. doi:[10.1037/0278-7393.25.3.664](https://doi.org/10.1037/0278-7393.25.3.664).
- Wilson, P. N., & Wildbur, D. J. (2004). First-perspective alignment effects in a computer-simulated environment. *British Journal of Psychology*, 95, 197–217. doi:[10.1348/000712604773952421](https://doi.org/10.1348/000712604773952421).
- Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities? *Trends in Cognitive Sciences*, 14, 138–146. doi:[10.1016/j.tics.2010.01.001](https://doi.org/10.1016/j.tics.2010.01.001).