

How directions of route descriptions influence orientation specificity: the contribution of spatial abilities

Chiara Meneghetti¹ · Veronica Muffato¹ · Diego Varotto¹ · Rossana De Beni¹

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Abstract Previous studies found mental representations of route descriptions north-up oriented when egocentric experience (given by the protagonist's initial view) was congruent with the global reference system. This study examines: (a) the development and maintenance of representations derived from descriptions when the egocentric and global reference systems are congruent or incongruent; and (b) how spatial abilities modulate these representations. Sixty participants (in two groups of 30) heard route descriptions of a protagonist's moves starting from the bottom of a layout and headed mainly northwards (SN description) in one group, and headed south from the top (NS description, the egocentric view facing in the opposite direction to the canonical north) in the other. Description recall was tested with map drawing (after hearing the description a first and second time; i.e. Time 1 and 2) and South-North (SN) or North-South (NS) pointing tasks; and spatial objective tasks were administered. The results showed that: (a) the drawings were more rotated in NS than in SN descriptions, and performed better at Time 2 than at Time 1 for both types of description; SN pointing was more accurate than NS pointing for the SN description, while SN and NS pointing accuracy did not differ for the NS description; (b) spatial (rotation) abilities were related to recall accuracy for both types of description, but were more so for the NS ones. Overall, our results showed that the way in which spatial information is conveyed (with/

without congruence between the egocentric and global reference systems) and spatial abilities influence the development and maintenance of mental representations.

Introduction

Spatial description and orientation specificity

The most common way to acquire environment knowledge is based on egocentric experience. When people navigate in the environment they gain spatial information in relation to their own body. The same happens when people use indirect methods to acquire spatial information, such as reading or hearing spatial descriptions of a path through an environment (such as a city or nature park), when spatial information is conveyed verbally using an egocentric reference frame and terms referring to the self, or body-centered (e.g. turn right, left, go straight ahead). This way of presenting information is said to be from a route perspective (Taylor & Tversky, 1992), as opposed to the survey perspective when information is presented using a global reference system (or allocentric reference frame), i.e. the canonical coordinates north, east, south and west.

Mental model studies have shown that people reading or hearing spatial descriptions form a mental representation of the corresponding state of affairs in the outside world (Johnson-Laird, 1983), preserving the physical properties of the space and the relationships between landmarks (Morrow, Stine-Morrow, Leirer, Andrassy, & Kahn, 1997; Rinck, Hahnel, Bower, & Glowalla, 1997), and organizing the information in their memory.

Studies based on spatial description learning have demonstrated that these mental representations may incorporate the perspective learnt (Meneghetti, Pazzaglia,

✉ Chiara Meneghetti
chiara.meneghetti@unipd.it

✉ Veronica Muffato
veronica.muffato@gmail.com

¹ Department of General Psychology, University of Padova,
Via Venezia, 8, 35131 Padua, Italy

& De Beni, 2011; Perrig & Kintsch, 1985) or be abstract, incorporating multiple views (Brunyé & Taylor, 2008; Taylor & Tversky, 1992). Other researchers, inspired by studies using visual inputs (e.g. Shelton & McNamara, 2001; McNamara, 2013 for a review), have focused on how spatial information is organized in memory and shown that, after spatial descriptions have been presented as spatial relations between objects (Avraamides, Galati, Pazzaglia, Meneghetti, & Denis, 2013) or as routes through an environment (Meneghetti, Pazzaglia, & De Beni, 2015; Shelton & McNamara, 2004; Wildbur & Wilson, 2008; Wilson, Tlauka, & Wildbur, 1999), they are represented in memory according to a specific orientation, which is determined by the initial imaginary view adopted by the protagonist walking along a path (when the description details imaginary movements in the second person).

In the above-mentioned studies, the task most often chosen to test spatial relations is the pointing task (also called judgement of relative direction; e.g. Shelton & McNamara, 2004), where participants imagine adopting positions in the environment and pointing in the direction of given landmarks. When a reference frame is provided by the protagonist's movements, participants adopt a reference frame aligned with the orientation first described and their pointing is more accurate when it involves landmarks aligned rather than counter-aligned with this initial orientation. For instance, Avraamides et al. (2013) recently asked participants to read narratives describing a protagonist's moves in the second person and the position of several objects around the protagonist (the learner), then the protagonist was described as turning through 90° to left or right with respect to his/her initial heading. In various experiments, participants imagined turning, or physically turned in the same direction as the protagonist or in the opposite direction. Performance in pointing tasks was more accurate and faster when the directions adopted during the tests were aligned with the learner's initial orientation¹ (see also Hatzipanayioti, Galati, & Avraamides, 2016).

The learner's initial view (based on egocentric experience) anchors the organization of the information being memorized, serving as a principal reference vector that helps to define an environment's intrinsic structure, i.e. the orientation ("top" and "bottom") of its mental representation. Once the principal reference vector has been established, the corresponding headings would be the most accurately accessed. Based on this assumption, egocentric

experience becomes predominant in influencing mental representations. Their maintenance seems to be organized according to an allocentric reference frame, however, because it is not updated when the observer moves (McNamara, 2003). This suggests that the on-line processing of egocentric-based information is organized for an enduring representation based on an allocentric frame of reference, i.e. the mental representation is based on relations between objects in the overall layout (McNamara, 2003, 2013; McNamara, Sluzenski, & Rump, 2008; Mou, McNamara, Valiquette, & Rump, 2004).

Analyzing the relationship between the egocentric and global reference systems in influencing the properties of mental representations of environments learned from spatial descriptions has recently attracted interest and some research has shed light on how egocentric experience and global coordinates can be combined by means of verbal indications (e.g. Gagnon et al., 2014; Meneghetti et al., 2015).

When learning from a description that presents environment information, we can combine our egocentric system (used to access spatial information) with a global system of coordinates that enables us to define the structure in which spatial relationships between landmarks (unrelated to the self) are represented. In a first study, Wilson et al. (1999) asked participants to read descriptions of simple paths (the U-shaped path by Presson, DeLange, & Hazelrigg, 1987) that presented the information from a route or survey perspective, i.e. the path was described using terms such as "you go forward" (in the second person) or "the path (...) extends northwards", respectively. The results showed that, for both types of description, pointing performance was more accurate when the imaginary view to adopt was aligned with the initial view and with the first segment of the path being described, and less accurate when the pointing task involved adopting a view counter-aligned with respect to the one initially adopted in the learning phase. So, whether these descriptions provide canonical information (i.e. go north) or not (as in the survey and route modes, respectively), a congruence is implicitly assumed between the individual's egocentric experience and the global reference system (both of which are north-up based) and the path, once it has been learnt, is mentally represented following a northward orientation.

In a further study by Meneghetti et al. (2015), participants were asked to listen to outdoor route and survey descriptions, and told that the imaginary exploration took place within a square area, starting from the bottom left-hand corner of the environment and heading upwards, i.e. they were given explicit information on how the overall environment was organized and moving mainly northwards (see also Shelton & McNamara, 2004). The results showed

¹ Some studies used both "orientation" and "perspective" as terms to indicate the direction in which information is encoded and represented in memory (e.g. Melinger et al., in press; Hatzipanayioti et al., in press). In the present paper, we used the term "orientation" to indicate the direction in which information is presented and organized in memory, and "perspective" to identify the type of description used (survey vs route; Taylor & Tversky, 1992).

again that participants performed better in northward-oriented than in counter-aligned pointing. So, providing verbal information consistent with the learner's egocentric and global reference frame (adopting a northward orientation) enabled a clear north-up mental representation to be formed, making the information organized according to the north-up view more readily accessible.

Very few studies have explored how an incongruence between egocentric experience and the global reference system may change the features of mental representations formed from spatial descriptions. Wildbur and Wilson (2008) asked participants to learn a path with and without canonical references in the first direction of travel (i.e. the path heads north, south, east or west) and described mainly using egocentric indications ("you walk on", "you turn left"); southward-heading descriptions thus represent a conflicting situation because the initial view faced in the opposite direction to the canonical north. When descriptions contained canonical directions, aligned pointing proved to be more accurate than counter-aligned pointing if the initial view and direction of travel were consistently northward. The northward alignment effect persisted—albeit less strongly—for descriptions heading east and west, but disappeared for those heading south. These results indicate that when egocentric experience is in conflict with the global coordinate system (when protagonists have to imagine embarking on a path heading south), their mental representation follows no specific orientation.

A similar manipulation was adopted by Gagnon et al. (2014), who (Experiment 1) asked participants to read route and survey descriptions (of outdoor environments) starting from canonical orientations heading north, south, east and west, and analyzing on-line and off-line aspects of their mental representations. The authors considered the learners' processing while reading (i.e. reading times) and features of their final mental representations (with sentences testing spatial relations from different perspectives). Participants were faster in reading (especially the first part of the description) and also in answering survey sentences for descriptions heading north and expressed from a route perspective than for the other orientations, and they were particularly slow for descriptions heading south. The authors concluded that a path starting from the south and heading north (the initial view) is congruent with the north-up orientation of the global reference system and this enables the information to be processed faster and a flexible mental representation to be formed, while descriptions heading south are more demanding and mental representations of them are less flexible. The authors confirmed the same advantage using a visually learnt environment (Experiment 2). After experiencing north-, south-, east- and west-oriented virtual environment navigation (shown by means of a compass), the response times were faster for

survey sentences in north-oriented navigation than for the other headings experienced, suggesting that the representation's properties have similar features when environment information is encoded verbally and visually (see also Shelton & McNamara, 2004). The results of this study are interesting because the authors separated the processing phases of description learning (even though they did not examine the properties of the final orientation) by testing imaginary views aligned and counter-aligned with the initial view and/or global reference system, for instance. This was only done by Wildbur and Wilson (2008). Gagnon et al. (2014) did suggest, however, that analyzing the phases of a representation's development is important for the purpose of assessing its properties. There is still a shortage of knowledge on the phases in which the properties of spatial representations develop. Our multiple testing phases and the use of different tasks (the first aim of the present study) therefore newly enable us to assess how mental representations develop and to define their features.

Gagnon et al. (2014) also said that southward descriptions are more resource-consuming. Individual factors, such as spatial abilities, may be able to explain why a given learning condition can be particularly demanding. People may use their spatial resources differently to manage spatial information that is aligned and counter-aligned with their initial view, and congruent or incongruent with the global reference system. Spatial abilities can, indeed, be a core factor capable of modulating the representation's properties, especially in the case of incongruence between egocentric experience and the global reference system.

Spatial descriptions, orientation specificity and spatial abilities

Several studies have demonstrated the central role of spatial skills in supporting the construction of spatial mental representations from environment descriptions. Spatial abilities are involved in generating, retaining and transforming abstract visual images (Lohman, 1988) and they comprise numerous distinct factors (see Hegarty & Waller, 2005 for a review). A recent classification (Uttal et al., 2013) identified four types of spatial ability derived from combinations of two dimensions, i.e. dynamic-static (transforming and manipulating vs perceiving objects) and intrinsic-extrinsic (to the objects concerned). The most often studied abilities used in spatial learning are part of the dynamic dimension. Dynamic-intrinsic abilities are used to mentally transform objects, by rotating 2D or 3D objects, for example (as measured with the Mental Rotations Test [MRT]; Vandenberg & Kuse, 1978), or mentally piecing objects together (as measured with the Mental Paper Folding Task; Shepard & Feng, 1972). Dynamic-extrinsic abilities are needed to imagine elements

occupying different positions in space (as measured with the Object Perspective-Taking [OPT] test; Hegarty & Waller, 2004).

Spatial description recall accuracy has been found related to mental rotation ability (tested with the MRT; Meneghetti, Gyselinck, Pazzaglia, & De Beni, 2009; Meneghetti, De Beni, Gyselinck, & Pazzaglia, 2013; Meneghetti, Ronconi, Pazzaglia, & De Beni 2014), and with perspective-taking ability (tested with the OPT; Meneghetti, Borella, Muffato, Pazzaglia, & De Beni, 2014). Spatial dynamic abilities involving rotation—based on object rotation and on the individual adopting rotated positions (measured with the MRT and OPT, respectively)—thus enable better-quality environment representations to be formed (Meneghetti et al., 2014).

Another individual factor related to spatial abilities (Cornoldi & Mammarella, 2008) and capable of supporting spatial description learning is visuo-spatial working memory (VSWM), devoted to maintaining and processing spatial information (Logie, 1995). Individuals with higher VSWM scores on the Corsi blocks task (Corsi, 1972) are better at recalling spatial descriptions (Meneghetti et al., 2009; Pazzaglia & Cornoldi, 1999). There is also evidence of both dynamic spatial skills (based on rotation) and VSWM concurring in modulating spatial description learning, since rotation ability—mediated by VSWM—predicts spatial recall accuracy (Meneghetti et al., 2014; Meneghetti, De Beni, Pazzaglia, & Gyselinck, 2011).

This analysis shows that individual spatial abilities can be fundamental to the formation and maintenance of mental representations acquired from descriptions, and their orientation properties. There is still a shortage of knowledge of how spatial abilities are involved in forming and maintaining orientation specificity. In a first study, Fields and Shelton (2006) explored how spatial abilities supported the orientation specificity of representations derived from virtual environment explorations presented from survey and route perspectives. Their results showed that spatial dynamic (rotation; measured with OPT and MRT) and VSWM (spatial span) task accuracy related to performance in judging the direction of landmarks from different views (using a pointing task), but perspective-taking ability had a particular role when headings misaligned with the initial view were tested. Although virtual exploration produces orientation-dependent mental representations similar to those deriving from survey and route descriptions of environments (Shelton & McNamara, 2004), only Meneghetti et al. (2015) have approached this question directly using spatial descriptions. In their study, after confirming that spatial information is mentally represented north-up (see the above-mentioned study), they newly demonstrated that—after learning environment descriptions—the ability to imagine adopting different

positions is fundamentally supported by rotation-based dynamic abilities (measurable with the MRT and OPT), and that perspective-taking ability is essential when it comes to adopting imaginary views counter-aligned with the north-up orientation. These results thus showed that spatial (rotation) abilities become fundamental when egocentric experience is congruent with the global coordinate system (north-up oriented), especially when individuals have to adopt (southward) views counter-aligned with the orientation represented in their memory. Another condition that can be particularly demanding—but has never been explored—is when there is no congruence in the spatial description between egocentric experience and the global coordinate system (as happens when individuals imagine embarking on a path heading south). The analysis of how the congruence (or incongruence) between the egocentric and global reference systems is costly in terms of spatial skills will be approached for the first time in the present study (the second aim of the current study).

Rationale and aim of the present study

This study aims to explore: (a) the development and maintenance of representations when path descriptions present information that make the egocentric and global reference systems congruent (or incongruent); and (b) how these representations are modulated by spatial abilities.

To approach these aims, two route descriptions were prepared (describing moves in the second person and locating the relations between elements from the participant's own point of view) based on the congruence or incongruence between the egocentric and global coordinate systems (inspired by Gagnon et al., 2014; Wildbur & Wilson, 2008). Specifically, one path starts from the bottom (bottom left-hand corner) of a square layout of an environment and proceeds northwards, in which case our egocentric experience is aligned with the global reference system (north-up); the other path starts from the top (top right-hand corner) of the square layout and heads south, so there is a misalignment because the participant's initial view faces in the opposite direction to the canonical north. Since the two types of description present information mainly from south to north, or from north to south, according to the global reference system, they are called SN and NS descriptions, respectively. The SN description thus presents a congruence between the egocentric and global reference frames, i.e. the protagonist (coinciding with the learner's imaginary view, though the learner does not move physically) goes forward towards the north—as in the case, for instance, when the protagonist being described as turning right congruently moves rightwards on a north-oriented cognitive map. In the NS description, on the other hand, there is an incongruence between the

egocentric and global reference frames because the protagonist goes forward towards the south of the environment (i.e. in the opposite direction). An example of this case is when the imaginary protagonist turning right incongruently moves leftwards on a north-oriented cognitive map, or moves rightwards when turning left. This latter type of description enables us to approach the question of the relationship between egocentric and global reference systems when they are not congruent.

Measuring participants' performance at different times newly provides information on how their mental representations develop and are fine-adjusted. Multiple measures were planned to assess the state of the representation (as Gagnon et al., 2014), and tests were therefore organized as follows: all participants listened twice to a description (oriented SN or NS) and were tested on their recall of the environment using a map drawing task after they had heard the description once (Time 1) and twice (Time 2) to assess how their mental representation developed and changed. Then participants performed a paper-and-pencil pointing task testing northward and southward orientations (SN and NS pointing, respectively) to assess how their final representation was organized.

Repeating the map drawing test enabled us to freshly approach the question of orientation specificity in relation to its development. This procedure is supported by previous studies showing that: (a) mental representations drawn from environment descriptions were poor and less flexible after a first reading than after a third (Bosco, Filomena, Sardone, Scalisi, & Longoni, 1996; Brunyé & Taylor, 2008) and they demanded a massive involvement of WM resources (Meneghetti, Pazzaglia, & De Beni, 2011); and (b) repeated testing produced a better recall accuracy and maintenance than spending an equivalent amount of time studying (see, for instance, Karpicke & Roediger, 2007; Roediger & Karpicke, 2006). Asking participants to draw two maps (after hearing the description once and then twice) enabled us to explore not only the improvement in accuracy, but also how the features of their mental representation changed, including whether its orientation specificity was already established after hearing the description once, and whether it was maintained after hearing it again.

Since the orientation specificity of mental representations involves individual spatial abilities (as shown previously by Meneghetti et al., 2014), several visuo-spatial measures were used to assess participants' dynamic abilities based on rotation (the MRT and OPT measures) and on multistep manipulations (the Minnesota Paper Form Board test, Likert & Quasha, 1941). Given the involvement of VSWM in learning spatial descriptions (Meneghetti et al., 2014, 2011), the backward version of the Corsi blocks task was also administered. We therefore newly assess the role

of spatial abilities in relation to the state of congruence (or incongruence) between the egocentric and global coordinate systems.

The following hypotheses were tested.

(a) *Spatial descriptions and orientation specificity*

SN descriptions in which egocentric experience is congruent with the global coordinate system (both north-up oriented) should enable the formation of a clearly north-up mental representation (as suggested in Meneghetti et al., 2014; Wilson et al., 1999). This should be detectable right from the start of the representation's construction (Time 1) and persist when the representation is further developed (Time 2). If the final representation is north-up oriented, then pointing that involves imagining facing north (SN pointing) should be more accurate than pointing that involves having to imagine facing south (NS pointing).

NS descriptions should generate different results from SN descriptions. If the initial view has a core role in influencing how the mental representation is organized (e.g. Wilson et al., 1999), then a conflict (incongruence) is generated when egocentric experience does not coincide with the global coordinate system (when the imaginary path starts at the top of the layout of the environment and heads south). If this happens, participants may try to realign their representation based on their egocentric experience—referring to their own north-up instead of following the southward direction proposed in the description—already in their first sketch (Time 1), and again when they further develop their mental representation (Time 2). When mental representations are tested with the final pointing task, they may also reveal no clear orientation specificity, showing no difference in pointing accuracy for SN and NS descriptions, as previously reported (e.g. Wildbur & Wilson, 2008).

(b) *Spatial descriptions, orientation specificity and spatial abilities*

We examined whether spatial abilities and VSWM support the development and maintenance of the orientation specificity of mental representations of routes, and how their involvement changes depending on the type of description (i.e. whether or not the reference systems are congruent). Using the map drawing task, we examined: (a) whether the involvement of spatial abilities is stronger at Time 1 than at Time 2 because sketching the representation is demanding (Meneghetti et al., 2011); and (b) whether this involvement is greater when there is an incongruence between egocentric experience and the global coordinate system (i.e. in NS descriptions) because this condition is more resource-consuming (Gagnon et al.,

2014) than in the case of congruence (i.e. in SN descriptions). Using the pointing task, we examined whether adopting imaginary views relies on spatial abilities in both types of description, with a greater involvement of spatial (rotation) and VSWM abilities in processing SN descriptions when participants had to imagine positions counter-aligned with the north-up orientation (as suggested in Fields & Shelton, 2006; and Meneghetti et al., 2014). We tested whether having to imagine adopting views facing south based on the NS description was spatial resource consuming *per se* because of the incongruence between egocentric experience and the global reference system.

In short, the present study analyses: (a) the development and maintenance of orientation specificity derived from spatial descriptions when the egocentric and global reference systems are (or are not) congruent; and (b) the involvement of visuo-spatial abilities in supporting the development and maintenance of this orientation specificity.

Method

Participants

Sixty native Italian speakers undergraduates attending the School of Psychology at the University of Padua (38 females, 22 males, M age = 20.30) took part in the experiment. They were assigned to two groups: 30 to hear a SN description (10 males); and 30 to hear a NS description (12 males).

Materials

Individual differences in spatial measures

Visuo-spatial working memory task. The backward Corsi blocks task involves repeating in reverse order increasingly long sequences of blocks presented by the experimenter (the sequences vary from 2 to 9 blocks in length, and two sequences are used for each length).

Spatial tasks

The Minnesota Paper Form Board (MPFB, Likert & Quasha, 1941) test involves choosing a figure, from among five options, that can be obtained by arranging a set of parts (31 items; time limit 8 min).

The Mental Rotations Test (MRT, Vandenberg & Kuse, 1978) involves identifying two abstract 3D objects, from among four options, that match a target object in a rotated position (20 items; time limit 8 min).

In the Object Perspective-Taking (OPT, Kozhevnikov & Hegarty, 2001) task, participants are shown a set of objects and for each item they are asked to imagine standing at one object, facing another, and pointing towards a third; answers are given by drawing an arrow from the center towards the edge of a circle (12 items; time limit 5 min).

All these spatial tasks have a good internal consistency ($\alpha = 0.80 - 0.90$; De Beni, Meneghetti, Fiore, Gava, & Borella, 2014).

Encoding phase

Spatial descriptions. Two descriptions from a route perspective of a fictitious zoo were used (written in Italian, adapted from Meneghetti et al., 2014). The zoo occupied a square area and included nine landmarks, four in the corners (the gate, the elephants, the chimpanzees and the dolphins), four halfway along the sides (the ticket booth, the ice-cream parlor, the playground and the lions) and one in the middle (the fountain). Participants were told that the landmarks were roughly 100 meters away from each other. Both route descriptions provide information about the overall layout of the zoo (i.e. that it is a square) and the main difference between the two descriptions lies in the starting point (the Entrance gate), which is in the bottom left-hand corner (in the SN description) and in the top right-hand corner (in the NS description). The first sentences in the descriptions provide information on how the overall environment is organized and the direction in which the path develops. Table 1 shows the two zoo layouts and the imaginary path covered according to the SN and NS descriptions. Starting from the two opposite (counter-aligned) points, the paths in both descriptions go towards the Playground, and from there to the Chimpanzees (Leg 1); then they turn 90° to the right to reach the Lions, then 90° right again towards the Fountain (in the opposite direction to the first leg), and from there to the Ticket booth (Leg 2). Finally, they turn 90° left towards the Elephants, then 90° left again (heading in the same direction as the first leg again) towards the Ice-cream parlor, ending at the Dolphins (Leg 3). Table 1 gives examples of sentences in the descriptions, which are of similar length (340 and 348 words for the SN and NS descriptions, respectively) and a pilot study ascertained that participants located the bottom left- and top right-hand corners of the zoo and recalled both descriptions equally well. The descriptions were recorded in MP3 files and each presentation lasted 2 min and 30 s).

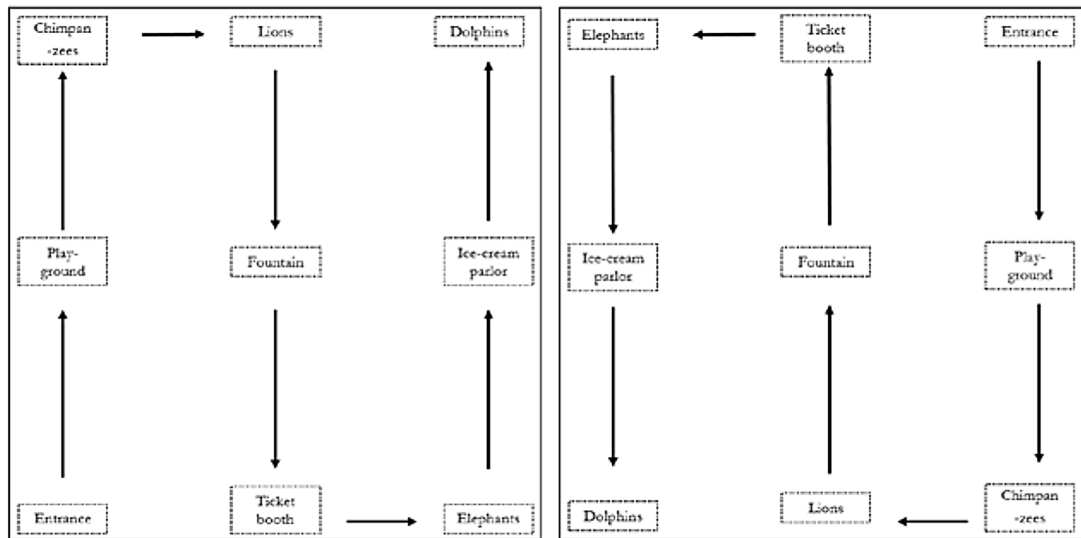
Recall phase

Map drawing. Two sheets of white paper were used to graphically represent the environment described at Time 1

Table 1 Environment layout and path: examples of sentences in the South-North descriptions (panel on the left) and North–South descriptions (panel on the right)

South-North description	North–South description
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Layout and path



Text excerpts

The little town of Podana has a zoo occupying a flat, square-shaped area. Now a path will be described that takes you on an imaginary visit around the zoo

You are at the Entrance gate *located in the bottom left-hand corner of the square*. The iron gate was made by a local craftsman

Walk straight on from the gate and after walking 100 meters you will see the Playground with games and colourful benches on your left

Keep going straight on for another 100 meters and you will come to the corner with the Chimpanzees’ cage; you can feed them if the keeper is there

Then *turn 90 degrees to the right* and walk on 100 meters until you find the Lions’ cage; they are famous because they are a rare species from Africa

At the Lions’ cage, *turn 90 degrees to the right* and keep walking another 100 meters and you will find the Fountain (...)

Example of pointing items

<p>Imagine standing at the Entrance and facing the Playground, then point to the Fountain (South-North oriented pointing)</p> <p>Imagine standing near the Chimpanzees, facing the Playground, then point to the Entrance (North–South oriented pointing)</p>	<p>Imagine standing at the Entrance and facing the Playground, then point to the Fountain (North–South oriented pointing)</p> <p>Imagine standing near the Chimpanzees, facing the Playground, then point to the Entrance (South-North oriented pointing)</p>
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(after hearing the description once) and Time 2 (after hearing it again).

Pointing task. This consists in items asking participants to imagine standing in a given place at the Zoo, facing one landmark and pointing to another (e.g. “Imagine standing at the Entrance and facing the Playground, then point to the Fountain”). The sentence was written at the top of the page and there was a circle below it with an arrow pointing upwards from its center, which represented the place where the participant imagined standing (the Entrance in our

example), the tip of the arrow indicated the place they were facing (the Playground), and their task involved indicating the direction of the target landmark (the Fountain) by drawing another arrow pointing outwards from the center of the circle.

Fifty-two items were prepared, 26 oriented south to north (SN pointing) and 26 north to south (NS pointing). Twenty-eight items concerned the lateral legs-14 each for legs 1 and 3 (7 oriented SN and 7 NS for each leg), and 24 items concerned the central leg 2 (12 NS and 12 SN). The

pointing direction for each item could be 0° , 45° , 90° , or 180° . Examples of the items are given in Table 1.

Procedure

Participants were tested individually during one session lasting around 90 min. They completed the spatial measures (backward Corsi task, MPFB, MRT, OPT task), which were presented in balanced order across participants. Then they were randomly assigned to one of the two description conditions (SN vs NS). They listened to the description once (Time 1) and were then asked to draw a map of the zoo and place the landmarks on a blank sheet a paper. Afterwards, they listened to the same description again (Time 2), and then drew another map on a new sheet of paper. In the last step, participants performed the pointing task (with the items presented in random order): they read each sentence, then judged the direction of the target landmark.

Results

Scoring

The participants' scores corresponded to the longest correctly-repeated sequence in the Corsi task, the number of correct answers (maximum 20) in the MRT and the MPFB task, and the mean absolute degrees of error in the OPT test.

As for the map drawing task, each map was scored using the Gardony Map Drawing Analyzer (GMDA; Gardony, Taylor, & Brunyé, 2015) open-source software for analyzing sketch maps and providing various outputs, including both configural (canonical and metrical) measures and measures based on the bidimensional regression method (Friedman & Kohler, 2003). Specifically, the GMDA compares the locations of landmarks on the map with the Cartesian coordinates of the target layout (taking for reference the target layout shown in Table 1), generating several parameters that reflect the landmarks' relative canonical locations (their positions vis-à-vis the cardinal directions NSEW) and metrical positioning (the distances and angles between them). Among the various measures provided by the GMDA, we opted to consider theta (a bidimensional regression output measure) and canonical organization (a configural measure).

Theta assesses to what extent participants rotated their maps, which can range from -90° to $+270^\circ$, in relation to the target layout (a range of 0° to 180° was used for this value in the analyses). This measure includes all kinds of rotation—with respect to the correct arrangement of the

target layout—adopted in the map drawing task or, in other words, to what extent the final map drawn by a participant differed from the orientation proposed in the description (see layouts in Table 1). Lower theta values (nearing 0°) mean that participants drew the environment without any rotation in relation to the actual one, i.e. in the SN description the entrance was located in the bottom left-hand corner of the square containing the zoo, while for the NS description the entrance was located in the top right-hand corner, and for both descriptions the other landmarks were arranged consistently with the path presented in Table 1. A medium theta value (i.e., from near 45° to near 135°) indicates that participants made a partial rotation, i.e. they rotated only a part of the environment, e.g. locating the starting point in the correct position but developing it mainly in a direction misaligned with the one shown in Table 1. A higher theta value (nearing 180°) means that the map drawn by a participant showed a path starting from the opposite point and going in the opposite direction to the one shown in Table 1, i.e. the entrance and the arrangement of the landmarks were (mostly or totally) counter-aligned with the path shown in Table 1; for instance, in the NS description, the entrance was located at the bottom (whereas it should be at the top), and the other landmarks were disposed in a south-north direction. The theta measure was chosen because it is sensitive in discriminating between participants whose representation of the environment was correct and those who re-aligned their representation to their initial view (achieving a higher theta in the NS description condition).

Canonical organization is an index of global accuracy obtained by comparing each landmark's position relative to all the other landmarks using NSEW directions (range: from 0 to 1, where higher scores indicate accurate landmark location recall). Since the distribution of this parameter is not normal, we considered the square root of the canonical organization (SQRT-CO) in our analyses (as suggested by Gardony et al., 2015). The accuracy of the canonical organization (and other indices obtained by the GMDA) is influenced by rotation, and our experiment contained a manipulation that made the maps drawn by participants susceptible to rotation, which consequently biased our canonical organization findings (as assessed using theta values). As suggested by Gardony et al. (2015), we therefore used the configural theta minimizing procedure, i.e. the maps were rotated, selecting the orientation that yielded the theta value closest to 0, and then the SQRT-CO was calculated. We opted to use the SQRT-CO because it is a sensitive measure for assessing the global accuracy of a drawing, considering how correctly each landmark is positioned in relation to all the others, based on canonical coordinates, and considering the number of missing landmarks.

Each drawing was thus scored as follows: each map was first scanned and made square (using Adobe Fireworks CS4 10.0), then uploaded in the GMDA, arranged with landmark labels, analyzed by pressing the “Preview” button to record the theta value, rotated until the theta value was minimized, and analyzed by pressing the “Calculate” button to obtain the configurational measure of the SQRT-CO.

For control purposes, the maps were corrected according to the traditional procedure (e.g. Brunyé & Taylor, 2008; Gyselinck & Meneghetti, 2011) based on scores awarded by two independent judges who gave one point for each landmark drawn/written in or near the right position on the target layout. To give an example, one point was scored if the Entrance was located in or near the bottom left-hand corner on a map derived from a SN description, and no points were awarded for landmarks wrongly located or omitted (maximum score 9).

For the pointing task we calculated the absolute angle of error in degrees based on the difference between a participant’s arrow and the right direction of the target landmark.

Preliminary analyses

We ascertained that the two groups (hearing NS and SN descriptions) did not differ in their scores for the spatial measures ($F_s < 1$, p_s from 0.55 to 0.94; see means for the whole sample in Table 4).

The scores awarded by the judges using the traditional method for scoring maps drawn after learning from descriptions correlated with one another ($r = 0.97$, $p < 0.001$) and with the SQRT-CO at both Time 1 ($r = 0.77$) and Time 2 ($r = 0.76$), confirming the validity of the GMDA as a map scoring procedure (Gardony et al., 2015).

Our analysis proceeded as follows: (a) the effect of orientation specificity was analyzed using ANOVAs on the

theta values of non-rotated maps, SQRT-CO values at Times 1 and 2, SN and NS pointing, exploring how accuracy changed as a function of description condition (SN vs NS); (b) the influence of spatial abilities on mental representations was analyzed using correlations and regression models on SQRT-CO and pointing accuracy.

Spatial descriptions and orientation specificity

Map drawing task

Map rotation. The 2 (Description orientation: SN vs. NS) × 2 (Time of map drawing: 1 vs. 2) ANOVA on the theta values showed the main effect of: Time, $F(1,58) = 11.31$, $p < 0.001$, $\eta_p^2 = 0.16$, where maps drawn at Time 1 ($M = 55.65$, $SD = 60.76$) was more rotated (vis-à-vis the orientation of the layouts shown in Table 1) than those drawn at Time 2 ($M = 31.32$, $SD = 52.18$); and Description orientation, $F(1,58) = 24.58$, $p < 0.001$, $\eta_p^2 = 0.30$, the maps being more rotated for NS descriptions ($M = 70.16$, $SD = 66.00$) than for SN descriptions ($M = 16.81$, $SD = 23.69$). The Description orientation × Time of drawing interaction was not significant ($F < 1$). These results indicate that the orientation of participants’ drawings was more rotated at Time 1 than at Time 2, and for NS descriptions than for SN descriptions. See Table 2 for descriptive statistics.

To see how many participants rotated their drawings as a function of Description orientation at Times 1 and 2, we created three groups based on theta values, i.e. no rotation (0°–44° of rotation), partial rotation (45°–134° of rotation), and complete rotation (values around 135°–180° of rotation). See Table 3 for the frequencies at Times 1 and 2 for each condition. At Time 1 [$\chi^2(2) = 11.99$, $p = 0.002$] the number of participants who did not rotate their drawings

Table 2 Means (M) and standard deviations (SD) of performance in map drawing (Theta and SQRT-CO parameters; SQRT-CO is a measure calculated after minimizing the rotation bias—i.e. the theta value) and pointing tasks by description condition (south-north vs north-south oriented)

Measure	South–North description		North–South description		Total	
	M	SD	M	SD	M	SD
Theta (map rotation index; 0°–180°)						
Time 1	26.65	34.77	84.65	67.55	55.65	60.76
Time 2	6.98	12.62	55.67	64.46	31.32	52.18
Total	16.81	23.69	70.16	66.00		
SQRT-CO (map accuracy index; 0–1)						
Time 1	0.66	0.18	0.68	0.15	0.67	0.16
Time 2	0.83	0.07	0.82	0.12	0.83	0.10
Total	0.74	0.13	0.75	0.13		
Pointing (0°–180° errors)						
South–North pointing	22.99	25.24	36.58	28.47	29.79	27.55
North–South pointing	36.78	38.94	36.97	33.27	36.87	35.93

Table 3 Number of participants who did not rotate (Theta: 0°–44°), partially rotated (Theta: 45°–134°), or completely rotated (Theta: 135°–180°) their drawings as a function of SN and NS descriptions and time (Time 1 vs Time 2)

	Route description							
	Time 1				Time 2			
	South–North (<i>N</i> = 30)		North–South (<i>N</i> = 30)		South–North (<i>N</i> = 30)		North–South (<i>N</i> = 30)	
	<i>N</i>	%	<i>N</i>	%	<i>N</i>	%	<i>N</i>	%
No rotation of drawing (Theta: 0°–44°)	23	76.7	12	40.0	28	93.3	17	56.7
Partial rotation of drawing (Theta: 45°–134°)	7	23.3	10	33.3	2	6.7	8	26.7
Complete rotation of drawing (Theta: 135°–180°)	0	0.0	8	26.7	0	0.0	5	16.7

(0°–44° group) was higher for SN ($N = 23$) than for NS ($N = 12$) descriptions, while the number of participants who completely rotated their drawings (135°–180° group) was higher for NS ($N = 8$) than for SN ($N = 0$) descriptions, but a similar number of participants made partial rotations in SN ($N = 7$) and in NS ($N = 10$) descriptions. Similarly, at time 2 [$\chi^2(2) = 11.29, p = 0.004$] the number of participants who did not rotate their drawings (0°–44° group) was higher for SN ($N = 28$) than for NS ($N = 17$) descriptions, while the number of participants who completely (135°–180° group) or partially (45°–134° groups) rotated their drawings was higher for the NS (45°–134°: $N = 8$; 135°–180°: $N = 5$) than for the SN (45°–134°: $N = 2$; 135°–180°: $N = 0$) condition. These results showed that the number of participants rotating their drawings was higher in the NS than in the SN group at both Times 1 and 2, confirming the previous analysis of variance.

Accuracy. The 2 (Description orientation) \times 2 (Time of map drawing) ANOVA on the SQRT-CO scores only showed the main effect of Time, $F(1, 58) = 72.34, p < 0.001, \eta_p^2 = 0.56$, where accuracy was better at Time 2 ($M = 0.83, SD = 0.10$) than at Time 1 ($M = 0.67, SD = 0.16$; see Table 2). No other main effects or interactions were found ($F_s < 1$).

Pointing task

A preliminary 2 (Description orientation) \times 2 (Type of pointing) \times 3 (Leg: 1 vs 2 vs 3) ANCOVA was run, inputting the SQRT-CO scores at Times 1 and 2 as covariates, to check the effect of map drawing accuracy on pointing performance. The results showed the main effect of SQRT-CO at Time 2, $F(1, 56) = 26.28, p < 0.001, \eta_p^2 = 0.32$, but not at Time 1, $F = 1.68, p = 0.20$, indicating that accuracy in terms of SQRT-CO at Time 2 was related to pointing task performance ($r = -0.64, p < 0.01$). Neither SQRT-CO at Time 1 nor SQRT-CO at Time 2 interacted with the other variables, however ($F < 1$ to $F = 2.60, p_s > 0.08$), confirming the assumption of a

parallelism—and for the final analysis we conducted a $2 \times 2 \times 3$ ANOVA.

The results showed the main effects of: Type of pointing, $F(1, 58) = 7.19, p = 0.01, \eta_p^2 = 0.11$, showing that it was easier to point in a SN direction ($M = 29.79, SD = 27.55$) than in a NS direction ($M = 36.87, SD = 35.93$); and Leg, $F(2, 57) = 7.91, p < 0.001, \eta_p^2 = 0.22$, showing that pointing errors for Leg 1 ($M = 27.37, SD = 28.41$) were more limited than for Leg 2 ($M = 35.58, SD = 30.82; p = 0.001$) or Leg 3 ($M = 37.04, SD = 35.99; p = 0.007$), which did not differ from one another. There was a significant interaction between Type of pointing \times Description orientation, $F(1, 58) = 6.42, p = 0.014, \eta_p^2 = 0.10$, showing that SN pointing ($M = 22.99, SD = 25.24$) was more accurate than NS pointing ($M = 36.78, SD = 38.94; p = 0.001$) after hearing a SN description (applying Bonferroni's correction the difference was considered significant $p \leq 0.01$); performance in SN pointing ($M = 36.58, SD = 28.47$) and NS pointing ($M = 36.97, SD = 33.27; p = 0.92$) was much the same after hearing a NS description, as shown in Table 2 and Fig. 1; and SN pointing ($p = 0.038$) and NS pointing ($p = 0.98$) performance did not differ between the

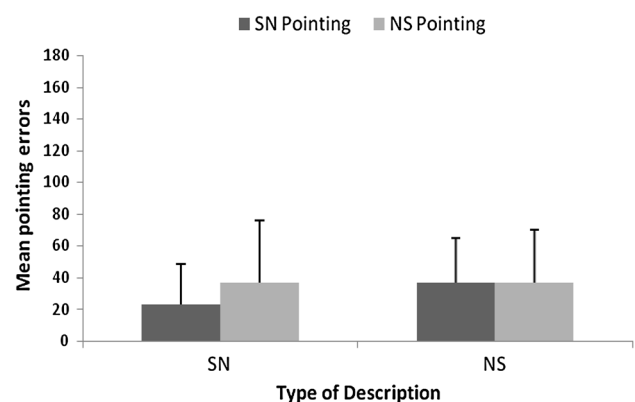


Fig. 1 Degrees of error in pointing as a function of type of route description (South–North vs North–South oriented) and Pointing (South–North vs North–South oriented)

SN and NS descriptions. No other significant interactions emerged ($F < 1$ to $F = 2.20$, $p = 0.12$).

To ensure that the lack of difference in pointing errors for NS descriptions was not due to the variability of the degree of rotation with which the environment was graphically represented, we identified two subgroups in the NS description condition, distinguishing participants whose map at Time 2 was not rotated ($N = 17$, Theta: $M = 4.61$, $SD = 4.03$) from those whose second map was – from partially to complet—rotated ($N = 13$, Theta: $M = 122.43$, $SD = 38.69$ —see Table 3): comparing the mean values showed that the two subgroups did not differ, neither as a function of type of pointing (SN pointing: unrotated drawings $M = 36.69$, $SD = 28.42$, rotated drawings $M = 36.43$, $SD = 22.89$, $p = 0.99$; NS pointing: unrotated drawings $M = 31.98$, $SD = 25.63$, rotated drawings $M = 43.50$, $SD = 35.45$, $p = 0.31$), nor as a function of the drawing’s rotation (rotated drawings: SN vs NS pointing, $p = 0.17$; unrotated drawings: SN vs NS pointing, $p = 0.29$).

Spatial descriptions, orientation specificity and spatial abilities

Correlations. Correlating map drawing accuracy scores (SQRT-CO, at Times 1 and 2) with the spatial measures showed that, after hearing SN descriptions, accuracy at Time 1 was significantly related to MRT and OPT, but no significant correlations were found at Time 2; after hearing NS descriptions, accuracy at both Time 1 and Time 2 was related to the backward Corsi task, MRT and OPT (see Table 4).

Correlating pointing performance (NS and SN) after hearing NS and SN descriptions with spatial measures showed that the backward Corsi task, MRT and OPT were

significantly related to pointing performance, except for OPT and SN pointing after hearing a SN description (see Table 4).

Hierarchical regression. To clarify to what extent spatial abilities support spatial recall accuracy, we developed: two hierarchical regression models considering map drawing accuracy, i.e. SQRT-CO at Times 1 and 2, respectively, as the dependent variables; and two models considering the NS pointing and SN pointing as the dependent variables. In all four models, in the first step, description orientation (as a dummy variable) and the backward Corsi task, MRT and OPT were considered as continuous variables and input as predictors (the MPFB was disregarded because it did not correlate with map drawing and pointing accuracy). In the second step, two-way interactions were input, including: Description orientation \times backward Corsi task; Description orientation \times MRT; and Description orientation \times OPT (see Table 5).

Map drawing. For the SQRT-CO at Time 1, we found a significant effect of the first step ($p < 0.001$), but not of the second, which accounted for 29 % of the variance: the OPT was significant ($\beta = -0.40$, $p = 0.004$), indicating that a better OPT performance (fewer degrees of error) were associated with more accurate map drawing at Time 1. No significant interactions emerged in the second step.

For the SQRT-CO Time 2, there was a significant effect of both steps ($p_s < 0.05$), which accounted for 26 % and 11 % of the variance, respectively. In the first step, MRT ($\beta = 0.29$, $p = 0.04$) and OPT ($\beta = -0.29$, $p = 0.04$) were significant: map drawing accuracy at Time 2 was associated with a better performance in the MRT (higher scores) and OPT (fewer degrees of error). In the second step, the Description orientation \times OPT interaction was significant ($\beta = 0.42$, $p = 0.03$), showing that map drawing accuracy at Time 2 was associated with OPT

Table 4 Means and standard deviations of each measure in the first column. Correlations between spatial measures and map-drawing accuracy (SQRT-CO)—Time 1 and Time 2—and pointing performance by description condition (SN vs NS oriented). Significant correlations are in bold type

	M (SD)	Map drawing (SQRT-CO)				Pointing task			
		South–North route description		North–South description		South–North description		North–South description	
		Time 1	Time 2	Time 1	Time 2	South–North Pointing	North–South Pointing	South–North Pointing	North–South Pointing
Corsi blocks task (backward)	5.45 (1.25)	0.13	0.11	0.38*	0.44*	-0.38*	-0.48**	-0.44*	-0.40*
MPFB	19.73 (4.21)	0.30	0.05	0.09	0.16	-0.16	-0.09	-0.23	10.24
MRT	9.42 (4.76)	0.42*	0.23	0.41*	0.53**	-0.36*	-0.44*	-0.50**	-0.52**
OPT	30.24 (20.84)	-0.42*	-0.11	-0.59**	-0.66**	0.31	0.54**	0.47**	0.58**

* $p < 0.05$; ** $p < 0.01$; MPFB minnesota paper form board, MRT mental rotations test, OPT object perspective-taking; negative signs have positive meaning: high map-drawing scores related to fewer degrees of error in the OPT; fewer degrees of error in pointing performance related to high scores in spatial measures (Corsi, MRT)

Table 5 Hierarchical multiple regression on map-drawing accuracy (SQRT-CO) at Time 1 and Time 2 and pointing performance (north–south vs south–north oriented). Significant values are reported in bold type

Predictors	ΔR^2	β	t	p
SQRT-CO time 1				
Step 1				
Orientation ^a		−0.01	0.12	0.90
Corsi task		−0.04	0.27	0.79
MRT		0.25	1.80	0.07
OPT		−0.40	3.02	0.004
	0.29 ($p < 0.001$)			
Step 2				
2-way interactions	0.04 (ns)			
SQRT-CO time 2				
Step 1				
Orientation ^a		0.05	0.38	0.71
Corsi task		0.05	0.33	0.75
MRT		0.29	2.07	0.04
OPT		−0.29	2.15	0.04
	0.26 ($p = 0.002$)			
Step 2				
Orientation ^a × Corsi		−0.11	0.60	0.55
Orientation ^a × MRT		−0.02	0.10	0.92
Orientation ^a × OPT		0.42	0.25	0.03
	0.11 ($p = 0.033$)			
Pointing south–north				
Step 1				
Orientation ^a		−0.32	2.80	0.01
Corsi task		−0.21	1.58	0.12
MRT		−0.27	2.01	0.05
OPT		0.16	1.25	0.22
	0.33 ($p < 0.001$)			
Step 2				
2-way interactions	0.00 (ns)			
Pointing north–south				
Step 1				
Orientation ^a		−0.05	−0.42	0.68
Corsi task		−0.17	1.38	0.17
MRT		−0.23	1.78	0.08
OPT		0.38	3.03	0.01
	0.39 ($p < 0.001$)			
Step 2				
2-way interactions	0.00 (ns)			

^a Orientation: 0 = north–south; 1 = south–north; MRT = mental rotations test, OPT = object perspective-taking

performance after hearing NS descriptions, but not after hearing SN descriptions, i.e. the ability to adopt a different perspective (measured by the OPT) predicted map drawing performance after learning from NS descriptions.

Pointing task. Both regression models produced significant results in the first step, but not in the second,

accounting for 33 % of the variance in SN pointing, and 39 % in NS pointing ($p_s < 0.001$). For SN pointing, the effect of Description orientation was significant ($\beta = -0.32$, $p = 0.01$), indicating that the SN description was related to SN pointing (consistently with the advantage of SN pointing after learning SN descriptions emerging from the ANOVA on the pointing task), and for SN pointing the effect of the MRT was significant ($\beta = -0.27$, $p = 0.05$), indicating that the fewer degrees of error in SN pointing was related with high MRT performance. For NS pointing, a significant effect of OPT emerged ($\beta = 0.38$, $p = 0.01$), indicating that NS pointing was related to OPT performance (fewer degrees of error).

Discussion of the results

The aims of the present study were to explore: (a) the development of mental representations, and the maintenance of their orientation specificity when path descriptions make egocentric experience (the imaginary initial view and direction of travel) congruent or incongruent with the global reference system; and (b) how the development and maintenance of these representations are differently modulated by spatial abilities.

Previous studies showed that: (a) mental representations derived from spatial descriptions follow a specific orientation determined by the learner's initial view (Meneghetti et al., 2014; Wilson et al., 1999), assuming a correspondence with the north-up based global reference system; when there is an incongruence (conflict) between the learner's egocentric (first) experience and the global coordinate system (north-up oriented), the mental representation has no clear orientation (Wildbur & Wilson, 2008), it takes longer to process, and it is less flexible (Gagnon et al., 2014); and (b) spatial dynamic abilities, and especially rotation skills, support spatial description learning (Meneghetti et al., 2009, 2013) and are involved in maintaining orientation specificity (as shown by Meneghetti et al., 2014). Starting from these premises, and with the aim of exploring the orientation specificity of mental representations drawn from spatial descriptions, and the involvement of spatial abilities in their development and the maintenance of their orientation, we manipulated the learner's initial view of the route described: when the starting point was in the bottom left-hand corner of the square layout representing the zoo, and the path developed mainly northwards (SN description), the learner's egocentric experience was aligned with the global reference system (both north-up); when the path started in the top right-hand corner and extended mainly southwards (NS description), the learner's egocentric experience and canonical system were not aligned, i.e. the initial view

imagined is counter-aligned with the canonical north. After completing a set of spatial tasks, participants listened to either SN or NS descriptions, and their recall was tested by asking them to draw maps after hearing the description once (Time 1) and twice (Time 2), to assess the definition and development of their spatial representations, and with pointing tasks in northward and southward orientations (SN and NS pointing, respectively) to assess the orientation of their final mental representations.

Spatial descriptions and orientation specificity

Our results showed that the orientation specificity of the route descriptions was influenced by the type of description heard and the type of recall task performed. In the map drawing task, the theta value (a rotation index) was higher and the accuracy score was lower after hearing the description once (Time 1) than after hearing it twice (Time 2). Repeating the test enabled us to establish not only that participants' maps were less accurate after hearing the description only once (as previously suggested by Brunyé & Taylor, 2008; and Meneghetti et al., 2011), but also that their performance was more subject to rotation variability than after hearing the description twice.

The theta values were also higher for NS descriptions than for SN descriptions, indicating that drawings referring to NS descriptions were more rotated than those referring to SN descriptions (as also confirmed by the analysis on the number of participants who rotated their drawings as a function of time and type of description). The greater rotation of the former may reveal participants' efforts to make their drawings converge with their own egocentric experience: when participants were obliged to imagine adopting a southward heading to travel along the path ("go straight ahead"), the direction of their body movement and the orientation proposed in the description were mismatched: in terms of the protagonist's imaginary movements, "going straight ahead" is interpreted as moving towards what is "in front" of the person (their own conceptual north), i.e. in the opposite direction to the southward orientation of the description.

The results of the pointing task showed, however, that the final organization in memory was clearly north-up oriented for SN descriptions, but not for NS descriptions. The Type of pointing \times Description orientation interaction showed that, after hearing SN descriptions, pointing while facing north (aligned with the initial view and the main direction of the imaginary path) was more accurate than while facing south, whereas for NS description there was no such difference. This confirms the typical alignment effect for SN descriptions (when initial view and global coordinate system are both north-up), but it is less clear what happened with NS descriptions (as in Wildbur &

Wilson, 2008) where the alignment effect is not clearly detectable. For both NS and SN descriptions, there was a beneficial effect if the initial view coincided with the first segment described, in which case the first leg was recalled better than the other two (as suggested by Gagnon et al., 2014; Wildbur & Wilson, 2008). Any such benefit did not affect the specific orientation of the mental representation in the case of NS descriptions, however. The specific analysis for the NS description, comparing participants who rotated their drawing (i.e. in SN direction) with those who made their drawing consistent with the description's orientation (i.e. no rotation) may be the way to clarify the representation's features. In fact, even if the two sub-groups did not differ significantly, the means descriptively suggest that participants who rotated their drawings had greater difficulty in solving pointing tasks, especially in the case of NS pointing. It therefore seems important to assess in future research whether participants represent the environment in a rotated modality, and how they manage it in approaching pointing tasks.

Taken together, our participants' map drawing and pointing results shed light on how mental representations derived from route descriptions (in which egocentric experience and the global coordinate system may or may not be congruent with one another) are sketched, defined and maintained. When routes were oriented mainly northwards (in terms of the initial view egocentrically experienced and the global reference system), representations were clearly defined from the start and maintained a north-up orientation.

This state of affairs changes, however, for representations referring to NS descriptions. Using verbal input based on an incongruence between their egocentric and the global reference systems, participants tended to be re-aligned with the protagonist's egocentric experience (as revealed by the rotation index of their maps), but in their final version they were not clearly oriented, and there was a greater variability in the rotation of their drawings depending on the orientation of the description. These results can be explained by the misalignment prompting an initial attempt to rotate the spatial information according to the protagonist's egocentric experience (moving away from the orientation proposed in the description and trying to recall it according to their own conceptual north), and the learner's subsequent failure to memorize the representation according to a north-up orientation.

It should be noted, however, that if egocentric experience is dominant in establishing the principal reference vector according to which the information is organized (McNamara, 2003, 2013), another emerging explanation for a representation with no clear orientation in the case of NS descriptions relates to participants' difficulties in imagining that they adopt a view counter-aligned with

respect to the direction in which they face (as suggested by Avraamides & Sofroniou, 2006), since it was more difficult to understand what was left and right for the protagonist when participants were physically misaligned with the protagonist's imaginary view. In further studies, it might be interesting to include a series of manipulations of participants' physical rotations matching or mismatching with the protagonist's view (as done by Avraamides et al., 2013) to identify the effect of the physical movement in retrieving information from different orientations (Hatzipanayioti et al., 2016); this would shed more light on the role of egocentric experience in the formation of the mental representation.

Another option is to consider studies using visual inputs (such as maps and navigation)—given that environment representations are orientation-dependent when both visual and verbal inputs are used (e.g. Shelton & McNamara, 2004), and they show an advantage of the northward heading orientation (Gagnon et al., 2014)—that can allow for manipulations concerning how to distinguish the influence of allocentric and egocentric frames in the case of verbally-conveyed spatial information. For instance, Meilinger, Frankenstein, Watanabe, Bühlhoff, and Hölscher (2015) manipulated the order of input presentation based on egocentric experience of an environment (navigation) or a global presentation view (map), showing the map before the navigation to one group of participants, and vice versa to another (and other groups were presented with only the map or the navigation). The results indicated that the representation was susceptible to the learning condition: when the map was seen first (and then the navigation was conducted), the representation followed a north-up orientation; when the navigation was done first (before the map was seen), the representation was aligned with egocentric experience. What reference frame is experienced first seems important in influencing the whole representation, so further studies using verbal input should devise a way to make experiences based on egocentric or global references prevail in order to distinguish between their respective roles in the formation and maintenance of mental representations.

Our findings also newly indicate that using different testing times and different test methods can shed light on how mental representations are developed and ultimately organized in memory. Map drawing and pointing tasks are useful measures for assessing different aspects of mental representations (Meneghetti, Borella, Gyselinck, & De Beni, 2012), the former clarifying how a mental picture looks (and is refined after hearing the same description again), the latter elucidating how the information used to form a mental picture can be managed adopting a different orientation. The map drawing results, in particular, indicate that the development of a mental representation was

sketched after a first hearing and reinforced on hearing the description again. This goes to show that approaching the question in terms of the different phases of information processing, and using different recall measures can elucidate how the representation develops and its different features. Further research is needed to clarify the features of mental representations during their development and maintenance. It will be useful to distinguish between the encoding and retrieval phases (as done in a preliminary work by Gagnon et al., 2014) to assess the different roles of the egocentric and global reference systems in the development of orientation dependence (given that both contribute to spatial learning, McNamara, 2003). In the retrieval phase in particular, employing different recall measures instead of the pointing task alone (to test the orientation in memory), and also testing verbally-expressed spatial relations (as done by Gagnon et al., 2014) and scene recognition (as done by Shelton & McNamara, 2004) from a protagonist's different views and/or perspectives (survey vs route) may assess representation flexibility (e.g. having access to information from another perspective from the one learnt), also in relation to how the information is encoded according to a particular orientation.

Although further research needs to be conducted, the analysis of individual spatial abilities in the present paper enabled us to better qualify how mental representations derived from route descriptions are sketched, developed and maintained, and what difference it makes when the starting point of an imaginary path is manipulated.

Spatial descriptions, orientation specificity and spatial abilities

Spatial dynamic abilities support the construction and maintenance of mental representations, albeit with some differences depending on the type of description, type of recall task and timing of their testing.

In the case of SN descriptions, map drawing correlated with rotation measures (assessed with the MRT and OPT) at Time 1, but with none of the spatial measures considered at Time 2. Pointing accuracy correlated with rotation measures (MRT and OPT, except for SN pointing not correlating significantly with OPT), and with VSWM (using the backward Corsi blocks task). After hearing NS descriptions, accuracy in recall tasks (map drawing at Times 1 and 2, and pointing) correlated significantly with rotation (MRT and OPT) and VSWM measures.

Only spatial dynamic measures based on rotation (MRT and OPT), but not on multistep manipulation (measured with the MPFB), correlated with recall task accuracy. This confirms that spatial abilities form a set of multiple competences that may be differently involved, depending on the environment to be learnt (e.g. Hegarty & Waller, 2005),

and rotation abilities become fundamental in supporting environment representation and its orientation specificity.

Judging from our correlations, NS descriptions appear to demand more spatial abilities. Our regression models better qualified the role of spatial (rotation) ability in relation to the timing of a test and the type of task involved. For all spatial recall tasks, performance was predicted by rotation measures, i.e. by the MRT (SQRT-CO Time 2; SN pointing) and the OPT (SQRT-CO Times 1 and 2; NS pointing). At the same time, the regressions showed that map drawing at Time 2 was particularly demanding after hearing NS descriptions (the OPT predicted map drawing accuracy at Time 2 for NS descriptions, but not for SN descriptions).

These results therefore showed that spatial abilities modulated the development and maintenance of spatial representations differently. Sketching a layout after hearing a route described only once (assessed with the map drawing task at Time 1) strongly involved spatial dynamic (rotation) abilities, whether SN or NS descriptions were learnt. When further defining the layout after hearing it described again (map drawing at Time 2), only the NS descriptions—when egocentric experience was not congruent with the global coordinate system—demanded a strong involvement of rotation skills (and perspective-taking in particular) in the graphical reproduction of the landmarks at the zoo.

Performance in the pointing task showed that spatial (rotation) and VSWM abilities are strongly involved in obtaining the final mental representation deriving from both types of description, and to much the same extent when learners adopt imaginary positions facing north or south. Having to imagine adopting a given orientation consumes spatial resources, irrespective of the type of description learnt. This result emerging from the pointing task partly contradicts previous reports of perspective-taking ability being prominent when mentally adopting positions misaligned with the learner's initial view (Fields & Shelton, 2006; Meneghetti et al., 2014). Given the paucity of our knowledge, further studies should explore the role of spatial abilities in modulating how mental representations are formed and maintained from descriptions in which egocentric experience may or may not be congruent with the global reference system before we rule out any differences in the effect of orientation as a function of the type of description.

To sum up, we showed that sketching and refining mental representations of any type of route description, and managing these representations from different imaginary viewpoints place a burden on spatial abilities and are resource-consuming. Spatial abilities also specifically support the mental representation's definition when learners are obliged to adopt an imaginary initial view that faces in the opposite direction to the canonical north.

Conclusions

The present study contributes to our knowledge of which conditions facilitate the development and definition of orientation specificity, and how spatial abilities support mental representations of an environment. In particular, we showed that:

(a) the initial imaginary view helped learners to develop and organize their mental representations with a clear north-up orientation when this egocentric experience was congruent with the global reference frame (as in the case of imagining starting from the bottom left-hand corner of a layout). When this congruence was lacking, learners tried to develop mental representations based on their egocentric experience (by rotating their drawings at Time 2), but the final version of their mental representation was not north-up oriented;

(b) spatial abilities (and rotation skills in particular) are fundamentally important in supporting the initial sketching, further definition and maintenance of a mental representation derived from either type of description considered here, but even more so when the route description makes the learner's egocentric experience incongruent with the global reference system.

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