What Makes the Difference When Learning Spatial Information Using Language? The Contribution of Visuo-Spatial Individual Factors

Chiara Meneghetti[1] and Veronica Muffato[2]

1 **Department of General Psychology, University of Padova, Padova, Italy**
chiara.meneghetti@unipd.it

2 **Department of General Psychology, University of Padova, Padova, Italy**

Abstract

Within the spatial cognition domain, increasing interest is being paid to identifying the factors able to support good-quality environment learning. The present study examined the role of several individual visuo-spatial factors in supporting representations derived from spatial language, using descriptions. A group of undergraduates performed visuo-spatial and verbal cognitive tasks and completed visuo-spatial questionnaires, then listened to descriptions of fictitious large-scale environments presented from survey (map-based) and route (person-based) views, and to non-spatial descriptions for control purposes. Their recall was assessed using a verification test and a graphical representation task. The results showed that: (i) verbal abilities support accuracy in recall tasks of spatial and non-spatial descriptions; (ii) visuo-spatial abilities, preferences (such as pleasure in exploring), and visuo-spatial strategies specifically support accuracy in recall tasks of spatial descriptions. The contribution of individual visuo-spatial factors varies, however, as a function of the type of description and the type of recall task: preference for the survey strategy seems more associated with performance in survey description recall and graphical representation. The results are discussed in the light of spatial learning models and in terms of their implications.

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1 Introduction

Spatial information can be acquired directly from sensorimotor experience, or indirectly from maps or virtual displays ([14, 26] for a review), or from spatial descriptions ([12] for a review). The last of these is commonly used, and involves reading from a device or hearing from a speaker the description of a path, or of the location of a landmark in an environment. The use of language to convey spatial information is attracting increasing attention in disciplines that deal with spatial information, such as engineering and geography. The interest lies in devising systems capable of handling spatial language in order to transfer knowledge of a route indications from a user to a robotic system [32], for instance, or systems capable of deriving a sketch-map from a speaker's spatial instructions [19]. Psychology studies such as ours can suggest ways for other disciplines to approach the spatial language issue. It has been clearly demonstrated that the processing of a verbally-conveyed spatial description leads to the formation of a mental model, i.e. an abstraction that resembles the structure of the corresponding state of affairs in the outside world [18], in which spatial relations between objects (landmarks) are mentally represented [2, 38, 13]. Mental models derived from the

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processing of spatial descriptions have been shown to have spatial features, though they may not perfectly resemble the mental representations acquired from visual input [31, 33]. A relevant question in this research domain concerns how to identify which individual features support a person's ability to produce mental representations. Among several others, individual visuo-spatial factors can have a major role, especially in predicting environment learning performance. It has been demonstrated [1, 14] that individual visuo-spatial factors (typically tested with paper and pencil tasks) represent small-scale abilities; the latter predict the ability to move in and represent the environment, which is an expression of large-scale abilities [35, 40, 41]. When individual verbal abilities were examined, on the other hand, they did not predict environment learning performance [14, 40]. Examining individual visuo-spatial factors (small-scale abilities) therefore enables us to predict environment learning accuracy (a large-scale ability), and this represent a relevant research question in the spatial cognition domain.

There are several aspects to take into account when considering the literature on how people mentally represent verbally-conveyed spatial information. For a start, there is the type of individual visuo-spatial factor, i.e. the various competences, including both cognitive abilities and self-reported preferences and strategies. Then there is the modality used to convey spatial information, i.e. from a route or survey perspective [38]. Route descriptions present landmarks and their relative positions from an egocentric perspective (or path view) and use an intrinsic frame of reference (e.g. "to your left", "behind you"). Survey descriptions present them from an allocentric perspective (or bird's-eye view) and use an extrinsic frame of reference, such as compass points (north, south, east, west). The literature review presented in the following paragraphs illustrates findings on spatial description learning considering: the type of visuo-spatial factor examined (objectively-tested cognitive abilities vs. self-reported attitudes and behaviors) in relation to type of description considered (survey vs. route).

Visuo-spatial abilities and spatial descriptions. Visuo-spatial abilities are needed to generate, retain and transform abstract visual images [20]. They comprise distinct aspects [16, 39], such as mental rotation, which is the ability to mentally rotate an object or oneself when imagining different views of a set of objects [15]. Another aspect responsible for individual differences concerns working memory, and particularly visuo-spatial working memory (VSWM), which is needed to process and retain visuo-spatial information. VSWM is generally tested on the recall of increasingly long series of elements, as in the Corsi blocks task [6]. Studies – mostly considering route descriptions – have shown that both mental rotation and VSWM abilities support the accuracy of mental representations derived from spatial descriptions [34, 25, 22, 23]. When people's recall of survey and route descriptions is compared, their final representations may differ [36], and this may at least partly relate to the cognitive abilities required. Learning a route description demands more VSWM resources than learning a survey description [2, 30, 10]. It is noteworthy, however, that the involvement of cognitive abilities also differs in relation to the type of recall task: performing graphical recall tasks after listening to a spatial description (e.g., asking participants to reproduce a map of the environment described) is more demanding on an individual's visuo-spatial cognitive resources than performing verbal tasks (e.g., answering questions about spatial relations) [22].

Self-reported visuo-spatial factors and spatial descriptions. By self-reported visuo-spatial factors, we mean a number of preferences, attitudes and strategies used when dealing with spatial information. People's visuo-spatial preferences consist in their inclination to orient themselves in an environment based on a mental map (survey/allocentric view) or from a personal view (route/egocentric view). These preferences influence their spatial description recall [23, 29]. Differences between survey and route description recall emerge in relation to the type of task used to test what a participant remembers. For instance, individuals with a stronger preference for the survey view performed better in a map drawing task after learning from a survey description [29]. Accuracy in performing spatial recall tasks is also influenced by self-reported strategy use, i.e. the type of procedure adopted to deal with certain recall demands [4, 11]. Concerning spatial descriptions, individuals report using more visuo-spatial strategies, mentally visualizing a path (route strategy) or forming a mental map (survey strategy), than verbal strategies based on repetition [23]. Comparisons between different types of description found survey description learning more associated with the use of survey strategies, while route description learning was associated with the use of both survey and route strategies [24].

The above-cited findings demonstrate the important influence of spatial (mental rotation) ability, VSWM, and self-reported (survey and route) strategy use on people's approach to spatial information, and their different modulatory effects as a function of the perspective learnt and the recall task performed. It should be noted, however, that the individual visuo-spatial factors were, in most cases, taken into account separately, and route descriptions were usually considered. Indeed, few studies examined the simultaneous role of several visuo-spatial factors in spatial description learning, and showed that both mental rotation and VSWM abilities, together with self-reported preferences and visuo-spatial strategies, play a part in supporting the recall of spatial (route) descriptions [25].

Visuo-spatial and verbal factors in spatial descriptions. When spatial information is conveyed verbally, people's verbal abilities naturally have a role too. In fact, when verbal working memory (VWM), i.e. the ability to process and maintain verbal information, was analyzed, it was found involved in the processing both of non-spatial and spatial (route) descriptions (though the latter specifically involved VSWM too) [30]. Reading comprehension, i.e. the ability to identify the meaning of a text, was also found to support performance in the recall of both non-spatial and spatial (route) descriptions, and the latter was additionally sustained by people's visuo-spatial abilities. This indicates that processing spatial descriptions requires the involvement of different verbal and visuo-spatial cognitive abilities, depending on the descriptions' format and type of content [12]. While the contribution of verbal abilities, such as VWM and reading comprehension, to the formation of a mental model has been demonstrated [7, 42], we do not know for sure how different visuo-spatial competences (both cognitive abilities and self-reported strategies) work in supporting the learning of descriptions with a spatial content, from a survey or route perspective, and how they emerge in different recall measures.

The novel aim of the present study was therefore to explore the role of visuo-spatial factors (in term of both cognitive ability and self-reported strategies) in supporting the learning of spatial descriptions, and the possibly different modulation effects of visuo-spatial factors as a function of the perspective learnt and the type of recall task administered. Given that gender is a source of variability in spatial task performance, and in spatial description learning [23], a large group consisting entirely of females was selected to participate in this study in order to avoid any confounding influence of gender. Participants were first assessed on their individual small-scale abilities by means of visuo-spatial tasks (testing their mental rotation and VSWM abilities), and verbal tasks (testing their reading comprehension and VWM abilities), and they completed a number of visuo-spatial questionnaires assessing their preferences in approaching the environment and pleasure in exploring (given the evidence of this positively influencing spatial learning [27]. Then they were assessed on their ability to represent spatial information by means of spatial descriptions: they listened to descriptions of fictitious large-scale environments in survey and route views, and to non-spatial descriptions for control purposes. The effect of perspective relates to the type of recall task administered [33, 12], so spatial recall was assessed using tasks both in a verbal format, by asking participants to judge the truthfulness of some relations (i.e. a verification test), and in a visuo-spatial format, by asking them to reproduce the arrangement of landmarks in a layout (i.e. a graphical representation).

We explored the different modulation of a set of individual visuo-spatial differences in environment representation. In particular, we expected accuracy in the recall of all descriptions to be supported by verbal abilities (as suggested in [7] due to the verbal format of the input used. After controlling for verbal abilities, we expected visuo-spatial cognitive abilities to specifically support spatial description learning (as suggested in [2, 25, 5]. Individual visuo-spatial preferences and strategies should also support the learning of spatial descriptions [2, 25]. Their contribution could differ as a function of the perspective learnt and/or the type of recall task administered. In particular, we expected the contribution of visuo-spatial factors to be stronger for active recall tasks (i.e. graphical representation) than in the recognition of the truthfulness of spatial relations (i.e. verification test) [21]. We also examined whether the effect of perspective related to the strategy used, such as the use of a survey strategy to memorize a survey description [24], or to complete a map-view task [25, 23].

2 Method

2.1 Participants

The study involved 173 female undergraduates (M age = 20.99, SD = 3.73), all native Italian speakers, in exchange for course credits. The study was approved by the local ethical committee for psychology studies.

2.2 Materials and procedure

Participants were tested individually in two sessions lasting an hour each. In the first session, they completed the verbal and visuo-spatial individual difference measures in a balanced order. The tasks and questionnaires are described below.

2.2.1 Individual differences in verbal and visuo-spatial measures

Verbal/Visuo-Spatial Working Memory tasks. The Backward digit span task [8] and backward Corsi blocks task [6] involve repeating in reverse order increasingly long sequences of numbers and blocks, respectively (from 2 to 9), that are presented by the experimenter. The final score is the longest correctly-repeated sequence.

Reading Comprehension Task (RCT [5]). The task consists in reading an argumentative text “the Rio conference” about climate change and pollution, and answering 10 multiple-choice questions on its content (maximum score: 10).

Perspective-Taking Task (PTT [9], adapted from [15]. The task consists in looking at a picture showing a configuration of 7 objects (on a piece of paper) and having to imagine standing at one object, facing towards another, and pointing in the direction of a third (always misaligned with respect to the respondent's view). The answer is given by drawing an arrow from the center towards the perimeter of a circle drawn on the paper, below the configuration of objects. The answer is scored in terms of absolute degrees of error (six items; time limit: 5 minutes).

Sense of Direction and Spatial Representation questionnaire (SDSR [28]). This comprises 11 items measuring 3 factors: (i) Sense of Direction – preference for survey mode (e.g., "Do you think you have a good sense of direction?"), 4 items; (ii) knowledge and use of cardinal points (e.g., "When you are outside, do you naturally identify cardinal directions, i.e., which way is North, South, East and West?"), 3 items; and (iii) preference for landmark and route mode (e.g., "Think about how you orient yourself in different surroundings. Would you describe yourself as a person who orients him/herself by remembering routes?"), 4 items.

Attitudes to Orientation Tasks scale (AtOT [9]). This comprises 10 items assessing pleasure in exploring (e.g., "I like to find new ways to reach familiar places"), with 5 positive and 5 negative items. For scoring purposes, the reverse score of the negative items was considered. Responses in the SDSR and AtOT were given on Likert scales ranging from 1 (not at all) to 5 (very much).

The internal consistency of all tasks and factors in the questionnaires were shown to be good (Cronbach's alpha from .71 to .86).

2.2.2 Descriptions, strategy use measures and recall tasks

In the second sessions, participants listened twice (for 6 minutes in all) to a non-spatial description, or to route or survey spatial descriptions (balanced across participants). After hearing each description participants scored their self-reported strategy use and completed the verification test and the graphical representation task. The descriptions, the strategy scale and the recall tasks are described below.

Descriptions

Non-spatial descriptions. Two descriptions were used ("grape harvest" and "olive oil", adapted from [28]). The descriptions describe the phases of wine production (from the grape harvest to bottling, and the differences between red and white wine), or olive oil production (from refining to bottling, and the different types of oil).

Spatial descriptions. Four descriptions of two fictitious outdoor environments were used ("tourist center" and "holiday farm", adapted from [23], two presented from a route and two from a survey perspective. In the survey version, the description first outlined the layout of the environment, then defined the relationship between landmarks using canonical terms (e.g. "north", "south-east"); in the route version, the description was given as if a person were walking along a route and the positions of the landmarks were presented as seen by the person using egocentric terms (e.g. "on the left", "turning right").

All descriptions were of similar difficulty (as tested in previous studies). They contained 14 units of information (in the non-spatial descriptions) or 14 positions of landmarks (in the spatial descriptions), and were all of similar length (between 288 and 309 words). Examples of the descriptions are given in Table 1. The descriptions were presented using .mp4 files (each presentation taking 3 minutes).

Table 1 Examples of non-spatial, route and survey descriptions; and examples of sentences in the verification test.

Non-spatial text (grape harvest)	Route description (tourist center)	Survey description (tourist center)
"[...] There are two types of vinification process, i.e. two different ways to make wine, for red and white wine. [...] Before bottling, the wine undergoes a crystallization process, when it cooled to sub-zero temperatures of around -5°C. This procedure lasts 2 days and enables the excess tartar to deposit so that it can be eliminated later."	"[...] Go straight ahead and you will soon see the tennis courts, which are used for a number of local competitions; they are on your left, at the end of the oak wood. Keep going as the road bends slightly to the right and, beyond the bend, on your left, you will see the hills that surround the whole area."	"[...] a dense oak wood, famous for its many centuries-old trees, stretches from north to south. This dense oak wood extends to the south as far as the tennis courts. At the southernmost tip of the lake there are hills stretching from east to west across the whole area of the tourist center."
Verification test		
During fermentation the new wine is stored at sub-zero temperatures. (False)	As you go towards the hills, you will find the oak wood on your right. (False)	The tennis courts are to the south of the hills. (False)

Strategy use scale. Three strategies were considered (as in [25]): survey ("I form a mental map"), route ("I imagine the path to cover"), and verbal ("I mentally repeat the information"). Participants were asked to judge their strategy use on a Likert scale, ranging from 1 (not at all) to 5 (very much).

Verification test. For each description, twenty true/false sentences were used, half of them true, the other half false (adapted from [23]). The sentences assess inferential information drawn from the non-spatial, route and survey texts (examples are given in Table 1). One point was awarded for each correct answer (maximum score: 20).

Graphical representation. For the non-spatial text, participants were asked to produce a diagram or a list containing the core units of information. For the survey and route texts, they were asked to draw a map of the environment described. In both cases, participants freely reproduced the information on a sheet of paper. They scored one point for each unit of information (in the non-spatial texts) or landmark (in the spatial texts) correctly reported (maximum score: 14).

3 Results

3.1 Correlations between variables

Concerning the correlations between the strategies used and the recall tasks (considering as significant the values $\geq .26$, corresponding to $ps \leq .001$ according to Bonferroni's correction), there was a significant correlation between the route and survey strategies and both the recall tasks on the route description (verification test-route strategy: $r = .30$; verification test-survey strategy $r = .28$; map drawing-survey strategy: $r = .33$; with $ps \leq .01$). There were also significant correlations for the survey strategy with survey description recall performance (verification test-survey strategy: $r = .31$; map drawing-survey strategy: $r =$

Table 2 Descriptive statistics and correlations for verbal and visuo-spatial individual difference measures and description recall tasks.

	1	2	3	4	5	6	7	8
1. Backward digit span (Verbal WM task)	–							
2. Backward Corsi (Visuo-spatial WM task)	.20	–						
3. Reading comprehension task	.04	.06	–					
4. Perspective-Taking Task	−.03	−.18	−.15	–				
5. SoD – preference for survey mode (SDSR)	.01	.18	−.01	−.14	–			
6. Knowledge and use of cardinal points (SDSR)	.05	.18	.06	−.07	**.40**	–		
7. Preference for landmark and route mode (SDSR)	.21	.03	.07	−.19	**.35**	.19	–	
8. Pleasure in exploring (AtOT)	−.06	.10	.10	−.16	**.70**	**.38**	**.36**	–
Non-spatial descriptions – Verification test	.14	.08	.10	−.12	.04	.11	.05	.09
Non-spatial descriptions – Diagram	.08	−.04	**.28**	−.14	−.05	−.08	.09	.07
Route descriptions – Verification test	.19	.19	.25	**−.26**	.16	.18	.24	.25
Route descriptions – Map drawing	.25	**.29**	.22	**−.35**	.19	.23	**.26**	**.27**
Survey descriptions – Verification test	**.27**	.21	.16	**−.26**	.10	.21	.17	.20
Survey descriptions – Map drawing	.22	.10	.22	−.18	−.02	.16	.10	.10
M	5.32	5.39	6.87	29.87	17.2	5.06	14.49	29.43
SD	1.29	1.27	1.78	21.51	4.86	2.23	2.29	8.83

Note. $N = 173$. The values of the correlations considered significant are shown in bold type, with $p \leq .001$. SDSR = Sense of Direction and Spatial Representation scale; AtOT = Attitudes to Orientation Tasks scale. For the Perspective-Taking Task we report the degrees of error.

.28, $p \leq .01$), but not with route strategy and survey description recall performance. No significant correlations emerged between verbal strategy use and survey or route description recall performance.

For the correlations between the individual differences in the objective of verbal or visuo-spatial measures and in the recall of the descriptions (see Table 2), we found that – for the non-spatial descriptions – only accuracy in the diagrams of the non-spatial text correlated with reading comprehension task performance (no other significant correlations involving recall accuracy were found); for the route descriptions, performance in both the verification test and the map drawing task correlated with PTT, and only the map drawing task correlated with the backward Corsi task, a preference for landmark and route modes (SDSR), and pleasure in exploring (AtOT) (with $ps \leq .001$). For the survey description, there were correlations between the backward digit span and PTT, but only with the verification test.

3.2 Regression analyses

Regression analyses were run to analyze the predictive value of verbal and visuo-spatial abilities and self-reported preferences and strategies on recall performance (in the verification test and graphical representation task) for all types of description (non-spatial, route and survey). Two independent judges scored performance in the graphical representation task and their scores correlated closely ($rs \geq .93$, $p \leq .001$), so the analyses were run on the scores awarded by the first judge. The order in which the variables were entered in the models was based on theoretical grounds. Given the verbal format used to present the environmental information [7] the contribution of visuo-spatial factors was analyzed after controlling for verbal abilities. Therefore, after controlling for verbal abilities (step 1), it was then we examined the contribution of visuo-spatial cognitive abilities (step 2), self-reported visuo-spatial preferences (step 3), and visuo-spatial strategies (step 4). The verbal strategy was not taken into account because it revealed no correlation with any type of description.

Table 3 Regression analyses for the verification tests and the diagram/list or map drawing tasks, by type of description (non-spatial, route and survey).

	Non spatial description					Route description					Survey description				
Predictors	ΔR2	Evidence ratio based on AIC	ANOVA on steps	β	p	ΔR2	Evidence ratio based on AIC	ANOVA on steps	β	p	ΔR2	Evidence ratio based on AIC	ANOVA on steps	β	p
Verification test															
Step 0															
Step 1: Verbal abilities	.03	1.41	.10			**.09**	**563**	**<.001**			**.09**	**743**	**<.001**		
Backward digit span (VWM)				.13	.08				**.18**	**.02**				**.26**	**<.001**
RCT				.09	.23				**.24**	**.001**				**.15**	**.04**
Step 2: Visuo-spatial abilities	.01	0.37	.38			**.06**	**53**	**.002**			**.07**	**83**	**.001**		
Backward Corsi (VSWM)				.03	.67				.11	.16				.12	.11
PTT				−.10	.21				**−.21**	**.005**				**−.21**	**.004**
Step 3: Self-reported visuo-spatial factors	.00	0.58	.35			**.04**	**.25**	**.004**			**.02**	**5**	**.02**		
Pleasure in exploring (AtOT)				.07	.35				**.21**	**.004**				**.16**	**.03**
Step 4: Strategies	.01	0.32	.44			**.05**	**15**	**.01**			**.05**	**25**	**.007**		
Route				−.12	.20				.16	.06				−.08	.30
Survey				.06	.49				.08	.34				**.25**	**.002**
Total R2	*.05*					*.24*					*.23*				
Graphical representation															
Step 0															
Step 1: Verbal abilities	**.08**	**219**	**<.001**			**.11**	**2993**	**<.001**			**.10**	**900**	**<.001**		
Backward digit span (VWM)				.07	.35				**.25**	**<.001**				**.22**	**.004**
RCT				**.28**	**<.001**				**.21**	**.004**				**.22**	**.004**
Step 2: Visuo-spatial abilities	.02	0.62	.23			**.12**	**1*10ˆ6**	**<.001**			.02	1.04	.13		
Backward Corsi (VSWM)				−.09	.24				**.19**	**.008**				.02	.78
PTT				−.11	.15				**−.29**	**<.001**				−.16	.06
Step 3: Self-reported visuo-spatial factors	.00	0.42	.63			**.05**	**53**	**.002**			.01	0.77	.22		
Pleasure in exploring (AtOT)				.04	.63				**.21**	**.002**				.09	.23
Step 4: Strategies	.01	0.23	.61			**.04**	**7**	**.02**			**.04**	**14**	**.01**		
Route				.09	.35				.02	.99				.08	.28
Survey				−.02	.84				**.27**	**.02**				**.18**	**.03**
Total R2	*.11*					*.32*					*.17*				

Note. N = 173; VWM = Verbal Working Memory; VSWM = Visuo-Spatial Working Memory; PTT = Perspective-Taking Test; AtOT = Attitudes to Orientation Tasks scale. Evidence ratio is based on the AIC of the various steps (each step is a model); the "ANOVA" column shows the comparison between one step and its predecessor. Significant values in bold type.

Predictors were entered at each step, and were only considered relevant if they contributed to reducing the model's Akaike Information Criterion (AIC). This index enables the relative quality of alternative models to be compared for a given dataset: the better the model, the lower its AIC [3]. Thus, the evidence ratio based on the AIC of the models and the F-test were used to confirm an improvement of the model from one step to the next. The R2 was also reported to account for the variance explained. All the models were checked for outliers (Cook's distance <1). First of all, in step 3 (self-reported measures) we added the SDSR factors (SoD – preference for survey mode, Knowledge and use of cardinal points, Preference for landmark and route mode), and Pleasure in exploring (AtOT). These SDSR factors were never found significant and in the final analyses only Pleasure in exploring was considered in step 3. The results are summarized in Table 3 and presented in Figure 1, which includes – for each dependent variable and for each step – the $\Delta R2$, the evidence ratio based on the AIC with respect to the previous step, the ANOVA comparing one step with its predecessor, and standardized β and p values.

Non-spatial descriptions. The predictors explained 5% of the overall variance in the verification test and 11% in the diagram/list task. No relevant predictors were found for the verification test, and the RCT was the only relevant predictor for the diagram/list task.

Route descriptions. The predictors explained 24% of the overall variance in the verification test, and 32% in the map drawing task. For the verification test, the relevant predictors were: backward digit span and RCT (step 1), PTT (step 2), Pleasure in exploring (step 3). The effect of using a route strategy tended to be significant. For map drawing task, the relevant

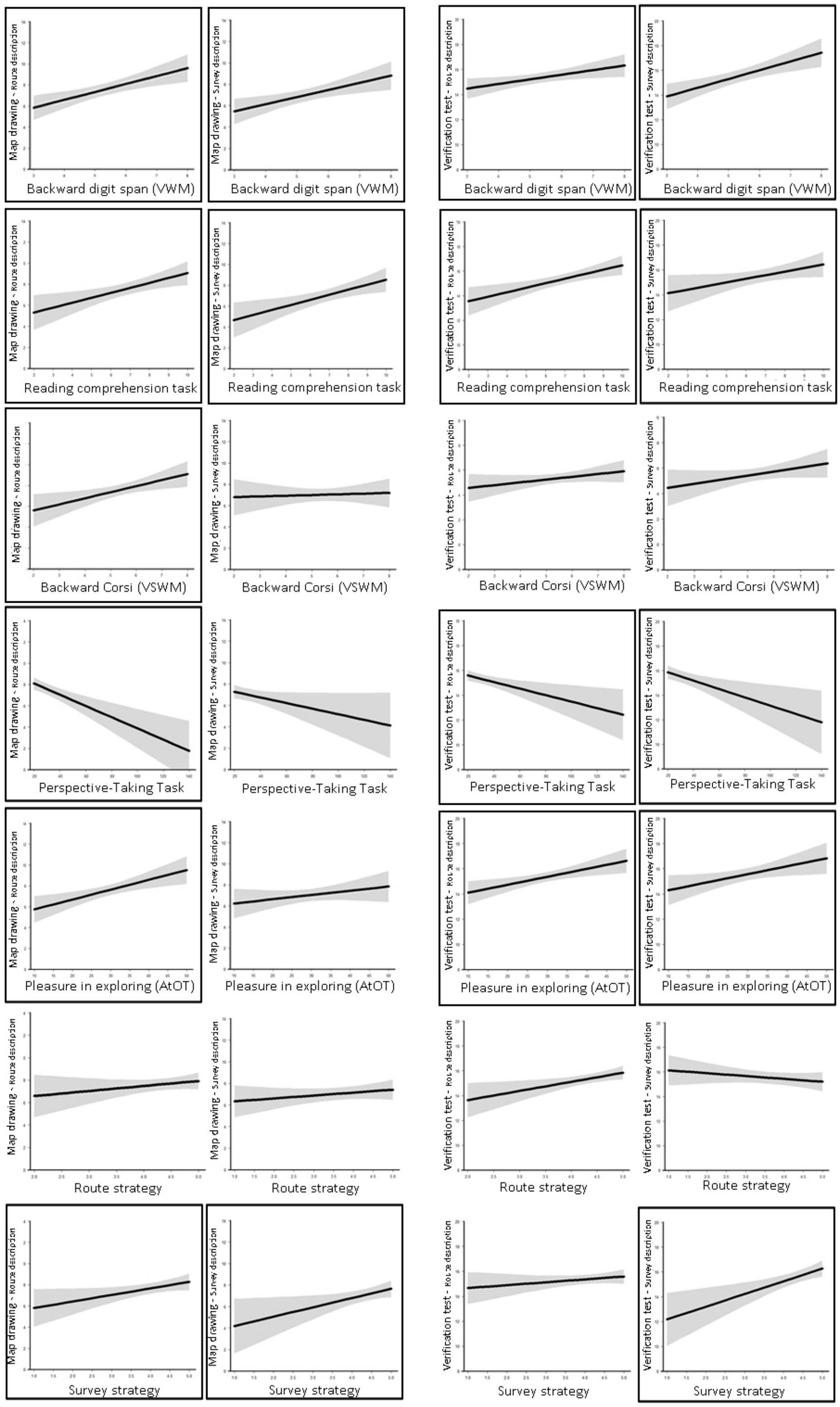

Figure 1 Effects of relevant predictors of route and survey descripitons accuracy in map drawing (first two coloumns) and verification test (second two coloumns). The figures with border indicate significant predictors $p \leq .05$).

predictors were: backward digit span and RCT (step 1), backward Corsi and PTT (step 2), Pleasure in exploring (step 3), and use of a survey strategy (step 4).

Survey descriptions. The predictors explained 23% of the overall variance in the verification test and 17% in the map drawing task. For the verification test, the relevant predictors were: backward digit span and RCT (step 1), PTT (step 2), Pleasure in exploring (step 3) and use of a survey strategy (step 4). For the map drawing task, the relevant predictors were: backward digit span and RCT (step 1), and use of a survey strategy (step 4).
It is worth noting that all steps were significant for the route descriptions (in all tasks) and for the survey descriptions (in the verification test), suggesting that adding the predictors improved the models (as shown by the evidence ratio based on the AIC). In the case of the map drawing task after presenting a survey description, the significant steps were step 1 (backward digit span and RCT) and step 4 (survey strategy).

4 Discussion and Conclusions

The present study was based on the following premises: (i) spatial language is commonly used to convey environmental information with different functions and aims [32, 19]; (ii) people's visuo-spatial competences influence the quality of their visually-acquired environment knowledge [14, 40]; and (iii) most of the contribution of individual visuo-spatial factors in supporting the acquisition of spatial description (especially from a route perspective) derives from the consideration of certain factors (such as cognitive abilities or self-reported preferences). There is therefore a shortage of evidence of the simultaneous contribution of cognitive abilities and self-reported preferences and strategies in supporting the recall of spatial descriptions from survey and route perspectives, as measured with different recall tasks. In particular, we explored whether it is possible to detect – beyond the contribution of verbal abilities – the specific role of visuo-spatial (cognitive and self-assessed) abilities, and possibly also their different role in predicting accuracy in recall performance, in relation to the perspective learnt and the modality used to assess it.

First, regression models showed that the learning of both visuo-spatial and verbal descriptions was supported by verbal abilities. In particular, reading comprehension ability (measured with the RCT) supported non-spatial description accuracy only when recalling information in a schematic form (not in the verification test). Ability in the RCT and the VWM task (backward digit span) supported route and survey description recall (in both the verification test and the map drawing task). This result shows that verbal abilities support the learning and recall of descriptions – as expected, given that a description is verbal per se, irrespective of the content [7, 42].

Second, for spatial descriptions there is a role for visuo-spatial abilities too, as well as for verbal abilities. The contribution of visuo-spatial cognitive abilities and self-reported preferences and strategies clearly emerged for the survey and route descriptions. In particular, spatial (rotation) ability predicted performance in the recall of route descriptions (in both the verification test and the map drawing task) and survey descriptions (in the verification test, while only a trend was found for the map drawing task), while only VSWM predicted map drawing performance after learning route descriptions. Judging from these results, learning route descriptions seems more demanding on WM (in both its visuo-spatial and its verbal aspects) than learning survey descriptions, especially when map drawing is used to test recall [2, 30, 10]. This supports the hypothesis that route description in association with an active reproduction is cognitively more demanding [2, 30, 10].

Further regression models showed that the role of visuo-spatial factors changes in relation to perspective and how recall is assessed, especially for visuo-spatial preferences and strategies. Concerning visuo-spatial preferences, the results revealed the predictive role of pleasure in exploring for route descriptions (in both the verification test and the map drawing task) and for survey descriptions (in the verification test). This result suggests that pleasure in exploring represents a positive personal attitude to approaching (moving in, and guiding others in) environments. The contribution of pleasure in exploring to how environment learning is approached seems to be relevant not only when an environment is conveyed visually [27]: having a positive general attitude to exploring an environment (by moving around in it) was newly related to the ability to represent verbally-conveyed spatial information. This attitude appears to be part of a particular spatial profile (since it also relates to sense of direction and a preference for using a survey mode) [9, 27] as also shown by the correlations in Table 2.

Concerning the visuo-spatial strategies that participants reported having used to understand and recall the descriptions they had heard, it is worth emphasizing that accuracy in both survey and route description recall were significantly associated with the participants' rating of their use of visuo-spatial strategies, but not with their use of verbal strategies (as found previously [25]. To be more specific, survey descriptions were associated with the use of a survey strategy in both the verification test (when participants were asked to judge the truthfulness of spatial relations between landmarks) and the map drawing (when they had to arrange the landmarks on a map). Route descriptions tended, on the other hand, to be associated with the use of a route strategy in the verification test (route view) and with the use of a survey strategy in the map drawing task (survey view). In other words, survey descriptions seem to be more associated with the use of a survey strategy, while route descriptions seem to be associated with the use of both survey and route strategies (as also shown by the correlations and previously suggested [24]). These results show the relation between self-reported visuo-spatial strategy use and spatial description recall accuracy (albeit with some differences depending on the perspective learnt). Therefore, it is not only when the use of visuo-spatial strategies is recommended that their use influences recall accuracy [37], but also when they are used spontaneously: learning a spatial description elicits the spontaneous use of strategies, and the survey strategy in particular.

The route descriptions warrant a few specific considerations. Our results indicate that learning from route descriptions is supported largely (and more than when learning survey descriptions) by visuo-spatial cognitive abilities and self-reported preferences and strategies. This was especially evident when recall was tested on graphical reproduction (in the map drawing task it explained a larger share of the variance, 32%, than the other models run) [2, 30, 10]. The route descriptions were also associated with the use of both route and survey strategies (in line with [25, 24]), suggesting that they prompt a greater degree of flexibility in people's approach to learning from this type of input. On the other hand, survey description learning, as assessed with a map drawing task, would be less demanding in terms of visuo-spatial cognitive abilities (since the step in the regression for visuo-spatial abilities and self-reported preferences did not improve the models).

We wish to acknowledge some of the limitations of the present study. One concerns the all-female sample considered. While this choice restricted the variability, our results are only applicable to young females (all university students in our case). Certainly, males will need to be considered in further studies before our findings can be generalized to the population as a whole. Another issue concerns our spatial descriptions, which were created ad hoc and balanced for length and quantity of information, but were fictitious, not representing real paths (like those shown on the Google Maps website, for instance). It would therefore be interesting to analyze to what extent our results can be generalized to descriptions of real paths or maps. It will also be interesting to explore to what extent spatial descriptions represent the "large scale": even though the passages present large-scale spatial information, we cannot say for sure that participants represent it in terms of large-scale exploration. Moreover, given the interesting role of strategy use in supporting graphical representation accuracy, further studies should more carefully consider criterion scores capable of detecting strategy use in mentally representing survey and route information. Finally, even if our results show the similarities and differences in the contributions of a set of cognitive abilities and self-reported preferences and strategies, it is important to bear in mind that cognitive abilities (both verbal and visuo-spatial) could share processes, and be part of the human intelligence construct (e.g. [17]), so more studies are needed to investigate the relationship between these predictors of environment recall performance.

Overall, these results can be considered consistent with spatial cognition models showing the relationship between small-scale abilities (i.e. individual visuo-spatial features) and large-scale abilities (environment learning [14]), considered here in terms of spatial descriptions. The novelty of our findings lies in that, beyond the contribution of verbal factors, multiple individual visuo-spatial aspects (both cognitive abilities and self-reported factors) need to be considered, and their influence varies as a function of the perspective learnt and the task used to assess recall. Certain learning conditions are more demanding than others (such as map drawing after learning from a route description, as opposed to a survey description), and show the role of certain preferences (such as pleasure in exploring) and strategy use (such as a survey strategy). The present study thus expands our theoretical understanding of how individual visuo-spatial factors influence mental representations of environmental information (in female undergraduates at least), and may have relevant implications in other related disciplines. For instance, for the software implemented by computer scientists to be capable of handling spatial language [32], it should – to some extent, at least – take the user's or speaker's individual differences into account. Our results indicate that the formation of a representation in map view after learning from a route description is more demanding, so such software should present descriptions or information using a survey view. It will be interesting to improve on this line of research by cooperating with other disciplines interested in spatial language.

To conclude, the present study points to the importance of analyzing individual factors (which include several relevant visuo-spatial competences, preferences and strategies) when examining the quality of mental representations of environments derived from spatial descriptions.

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