Journal of Environmental Psychology 78 (2021) 101708

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Finding the shortest path in a familiar environment: A comparison between describing and walking a path after accounting for the role of individual factors

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ARTICLE INFO

Handling editor: L. McCunn

Keywords:
Familiar environment
Shortest path finding
Spatial description
Visuospatial ability
Sense of direction
Navigation

ABSTRACT

Finding the shortest path to a destination is a refined navigation ability little explored as yet in familiar environments. The present study examined this ability when walking or describing the path, and how performance relates to individual differences. Sixty-seven undergraduates familiar with the area around their campus were asked to find the shortest path to a destination by walking there or describing it in writing. Several visuospatial tasks and questionnaires were administered. It emerged that shortest path finding performance was supported by familiarity and sense of direction. After accounting for these individual factors, participants performed better when walking than when describing a path. Overall, the results showed that retrieving spatial knowledge about familiar environments relates to individual differences and recall condition, walking a path being easier than describing it.

1. Introduction

People can form refined mental representations of familiar environments like a hometown or university campus (e.g., Evans & Pezdek, 1980; Foley & Cohen, 1984; Iachini et al., 2009; Kirasic et al., 1984; Thorndyke & Hayes-Roth, 1982). The quality of such representations is often tested with tasks that involve managing spatial information, such as estimating distances (e.g., De Goede & Postma, 2015), pointing in a given direction (e.g., Meneghetti et al., 2017), or locating landmarks (e.g., Meilinger et al., 2016), whereas path finding tasks have rarely been used. When identifying the shortest path to a destination in a given environment, we know that familiarity with it improves performance (Li & Klippel, 2016), even though people more or less familiar with the environment may perform equally well in pointing and landmark locating tasks (Muffato & Meneghetti, 2020). Undergraduates familiar with their university campus proved capable of judging the length of verbally-described paths, even without moving (e.g., walking) in the environment (Meneghetti et al., 2017), so spatial language could be used to assess shortest path finding skills. We know that environment representations can be formed from spatial descriptions (Gyselinck & Meneghetti, 2011), and extracted by verbal production (giving directions), with an impact on navigation efficiency (Daniel et al., 2003). It is unclear, however, whether shortest path finding tasks performed by describing the path in words and by walking in the environment differ in terms of the path chosen. A study by Hölscher et al. (2011) compared people's walking in the environment with their descriptions (for themselves and others) of the shortest path to a familiar place in their hometown. It emerged that walking produced shorter and more complex paths (more streets and turns) than descriptions. The Authors concluded that, while walking, people systematically chose routes appearing to lead as directly as possible towards their destination (helped by visual directional cues), whereas the routes they described were less complex and possibly longer (especially when intended for other people). There were no effects of familiarity or individual differences, i.e., visuospatial working memory (VSWM) or self-perceived sense of direction (the ability to orient oneself in the environment). This may be due to the small sample involved, however, since further studies examining familiar environments with larger samples found a role for both familiarity and individual visuospatial differences (e.g., De Goede & Postma, 2015; Meneghetti et al., 2017). The influence of the latter may depend on the recall tasks used: good sense of direction was found associated with a better shortest path finding performance, and visuospatial

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https://doi.org/10.1016/j.jenvp.2021.101708
Received 8 June 2021; Received in revised form 9 September 2021; Accepted 8 October 2021
Available online 10 October 2021
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abilities with map drawing and pointing task performance (Muffato & Meneghetti, 2020).

Given these premises, the present study aimed to examine people's ability to identify the shortest path to a destination in a familiar environment by walking there or describing the route they would take, and the part played by individual factors. Participants' degree of familiarity with landmarks and individual visuospatial factors (De Goede & Postma, 2015; Meneghetti et al., 2017) were taken into account. Multiple measures were used to assess basic mechanisms (VSWM), higher-level visuospatial abilities (mental rotation and perspective taking), and wayfinding attitudes (sense of direction, pleasure in exploring, spatial anxiety) as they relate to environment learning and their role differs as a function of the task involved (Hegarty et al., 2006; Meneghetti et al., 2021). Investigating familiar environment representations, instead of new environment learning (Meneghetti et al., 2021), enabled us to focus on the retrieval phase as the encoding phase had already taken place. It is worth comparing the walking and describing conditions because the way information is retrieved while walking in an environment (in a situated condition) may differ, in terms of accuracy and the involvement of individual factors, from when spatial information is retrieved from memory alone.

We expected participants to be more accurate in finding the shortest path when walking than when describing it because they could be facilitated by being situated in the environment (Hölscher et al., 2011). At the same time, studies on neural pathways suggest a greater hippocampal activation in better navigators than in less able navigators moving towards a destination in a familiar environment (Wolbers & Hegarty, 2010). Situated walking may be associated with a brain activation capable of functionally supporting performance. Differences between walking and describing a path were (newly) investigated after accounting for the role of individual factors, as performance may also relate to self-reported degree of familiarity with the environment (Muffato & Meneghetti, 2020) and individual visuospatial measures (Meneghetti et al., 2017).

2. Method

2.1. Participants

A sample of 72 undergraduates volunteered for the study in exchange for course credits. We ascertained that all participants: i) had started coming to the area after enrolling at university (none were city residents); ii) had been doing so for at least a year (*Mean* months = 27, *SD* = 9.05); iii) regularly attended their courses; iv) moved around the area on foot or by bicycle; v) rated as >5 (on a scale from 1 to 7) their familiarity with the 8 buildings involved in the shortest path finding task (these 8 buildings were chosen from among 14 considered in a pilot study because they had been awarded scores for familiarity of >5). Five participants rated their familiarity with the buildings as ≤5 and were excluded, leaving a final sample of 67 undergraduates (44 females, 23 males; *Mean* age = 22.04, *SD* = 1.52) very familiar with the 8 buildings ($M = 6.29$, $SD = 0.59$).

Hypothesizing an underlying d=.50 effect between the two main conditions (walking vs. describing), a power analysis was performed using the "simr" package (Green et al., 2016). A binomial mixed model with participant and path as fixed effects, and condition as the main effect (see Results) was simulated 10000 times with different sample sizes. The results showed that 65 participants sufficed to detect a significant difference ($p < .05$) between the two conditions (i.e., power >.80). As our final sample included 67 participants, we also ran a retrospective power analysis simulating this sample size, obtaining a power of .84.

2.2. Measures

2.2.1. Visuospatial working memory tasks

Two tasks were used: the *backward Corsi Blocks task* (adapted from Corsi, 1972; Mammarella et al., 2008, test-retest reliability: r = 0.74), and the *Jigsaw Puzzle Test* (JPT; De Beni et al., 2008; test-retest reliability: r = 0.83). The Corsi blocks task involves repeating sequences of blocks (from 2 to 9) on a board tapped by the experimenter, in reverse order. The test stops when respondents fail to repeat both sequences of the same length. The score is the maximum number of blocks correctly recalled (score 0–9). The JPT involves mentally reconstructing puzzles (from 2 to 10 pieces) depicting highly-familiar objects and saying where to place the pieces on a grid. The score is the sum of the pieces in the three most complex puzzles correctly solved (score 0–29).

2.2.2. Visuospatial ability tasks

Two visuospatial tasks were used (in shortened versions with good psychometric properties α = .80–81; De Beni et al., 2014): the *Short Mental Rotations Test* (sMRT, adapted from Vandenberg & Kuse, 1978); and the *Short Object Perspective-Taking task* (sOPT, adapted from Kozhevnikov & Hegarty, 2001). The sMRT involves finding two of four 3D objects (combinations of cubes) that match the target one, but in a rotated position (10 items; time limit 5 min). One point is awarded for each item in which both correct figures are identified (max score 10). In the sOPT, respondents imagine being at one object in a configuration of 7 objects, facing another, and pointing to a third by drawing an arrow from the center towards the edge of a circle (6 items; time limit 5 min). The mean of the absolute angular error is calculated (max 180°).

2.2.3. Wayfinding attitude questionnaires

Three questionnaires were used (from De Beni et al., 2014; good psychometric properties: α = .70-0.87). The *Sense of Direction and Spatial Representation scale* (SDSR; adapted by Pazzaglia et al., 2000; 13 items; max score 65) measures an individual's self-assessed sense of direction (orientation, knowledge and use of cardinal points, and spatial preferences). The *Spatial Anxiety scale* (SAS, adapted by Lawton, 1994; 8 items; max 48) assesses the anxiety experienced in wayfinding situations. The *Attitudes toward Orientation Tasks scale* (AtOT; 10 items; max 60) measures people's pleasure in exploring places. Each questionnaire is answered on Likert scales (from 1 to 5 for the SDSR; from 1 to 7 for the SAS and AtOT), and total scores are calculated from the sum of the items.

2.2.4. Shortest path finding

This involved finding the shortest path to four destinations, two by walking and two by describing the path. The four paths involved pairs of all 8 familiar buildings, and there were multiple ways to go from one building to the other (see Fig. 1 and Supplementary material Part 1). Scores were calculated dichotomously for each route: participants scored 1 point if they walked/described the shortest path, and 0 otherwise (maximum score 4, 2 for walking and 2 for describing). The experimenter and a second judge read participants' written descriptions and consistently identified the path described in 88% of cases. When they disagreed, they jointly decided on the score to award. Respondents' descriptions proved clear and easy to classify, and all adopted a route perspective (e.g., "turn left at the bridge").

2.3. Procedure

Participants signed the consent form and completed the preliminary questionnaire ascertaining their familiarity with the area. Then they completed the shortest path finding task, walking two paths and describing two (the paths and task conditions were counterbalanced across participants). In the walking condition, the experimenter took participants to the starting point of a first path, showed them a picture of the destination landmark, and asked them to walk there, going the shortest way from one building to another. Then the experimenter took

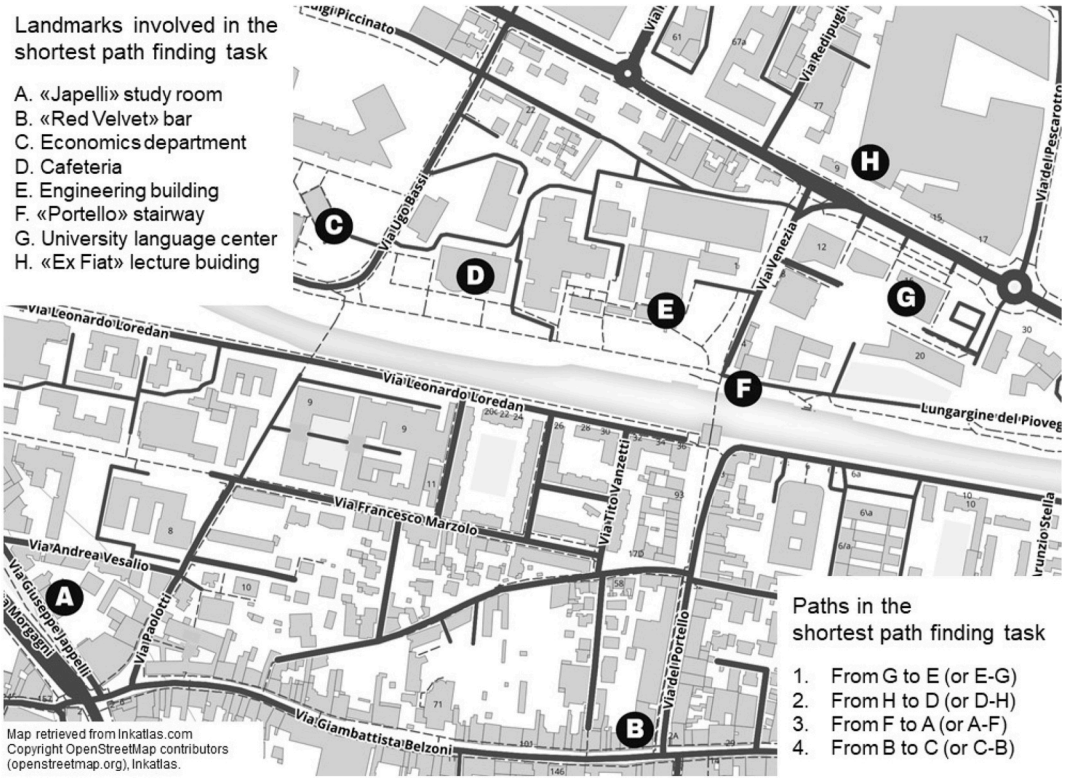

Fig. 1. Map of the familiar area (not shown to participants) with the 8 landmarks (letters A to H).

them to the starting point of a second path, and the procedure was repeated. As participants walked to their destinations, the experimenter walked immediately behind them, recording the path. In the describing condition, participants in the lab wrote a description of the two paths on a sheet of paper showing pictures of the origin and destination landmarks. Then they completed all the visuospatial tasks and wayfinding attitude questionnaires in a balanced order. Finally, to ensure that participants really knew where the 8 buildings were, they located them on a sketch map of the area (landmark locating task). Completing all these tasks in the lab took up to 90 min, and the path walking phase around 30 min.

3. Results

All analyses were run using R (R Core Team, 2019). See the supplementary material (Table S1, Part 2) for the descriptive statistics and correlations between variables. Global accuracy in the landmark locating task (from 0 to 1, Gardony et al., 2016) was ≥80, confirming participants' good familiarity with the landmarks. Shortest path finding performance was better in the walking condition (56%) than in the written descriptions (35%).

Generalized binomial regression models were used to examine the relations between the variables and shortest path finding accuracy. A stepwise approach was adopted to enter the predictors in the model (continuous predictors were standardized). A variable was only retained in subsequent models if it lowered the AIC (Akaike Information Criterion; Wagenmakers & Farrell, 2004) and BIC (Bayesian Information Criterion; Schwarz, 1978) by at least 3 units (see Table S2 in supplementary material, Part 2). If not, it was considered negligible and disregarded. Participants were entered in a baseline model (m0) as random factors (because they performed multiple shortest path finding tasks), and so were the paths (to control for the influence of their intrinsic difficulty on the results). The first variables entered were age (m1) and gender (m2) (Meneghetti et al., 2017), but they did not consistently lower the AIC or BIC. Mean familiarity with the landmarks (m3) (Muffato & Meneghetti, 2020) lowered both indices and was retained in subsequent models. Cognitive abilities were considered as basic mechanisms (VSWM - Corsi Blocks task [m4], JPT [m5]) or higher-level abilities (sMRT [m6] and sOPT [m7]), but neither lowered the AIC and BIC, so they were excluded. Then wayfinding attitudes were entered. The SDSR (m8) lowered both indices and was retained, while the SAS (m9) and AtOT (m10) did not and were excluded. The path finding condition (walking/describing, m11) lowered both indices. The interaction between the predictors (familiarity × SDSR [m12], SDSR × path finding condition [m13], and familiarity × path finding condition [m14] did not lower the AIC or BIC. No differences emerged in the selection of predictors because of the order of their inclusion in the model. The final model thus included only familiarity, SDSR, and path finding condition as predictors of performance in the shortest path finding tasks.

The results obtained with the final model showed a significant effect of the three predictors, which explained 15% of the variance (43% including random effects). The effect of each parameter was calculated using odds ratios, which correspond to the change in the odds given an increase of 1 point in the specific predictor variable (Bland & Altman, 2000). The probability of finding the shortest path was influenced by familiarity (OR = 1.42, 95% CI [0.99, 2.07], $p = .05$), and SDSR scores (OR = 1.67, 95% CI [1.19, 2.57], $p < .01$). Participants also found the shortest path more frequently when walking than when describing a path (OR = 3.25, 95% CI [1.82, 6.97], $p < .001$).

4. Discussions and conclusion

This study examined undergraduates' ability to find the shortest path between two places in a familiar environment (university campus), comparing their performance when walking the paths or describing them, and taking individual differences (in degree of familiarity and visuospatial measures) into account. Familiarity with the landmarks and self-reported sense of direction predicted accuracy in the shortest path finding task, while visuospatial measures did not (though they correlated with accuracy to some degree). After accounting for individual

factors, shortest path finding performance was better for walking than for describing the paths.

Our results show a role for individual differences in shortest path finding performance in a familiar environment: although all undergraduates were familiar with the environment, those rating their familiarity with the buildings higher were better able to find the shortest path. This is in line with previous evidence (Muffato & Meneghetti, 2020) of mental representations becoming more refined the greater the exposure to an environment. Participants' visuospatial abilities and wayfinding attitudes related to their shortest path finding performance (De Goede & Postma, 2015; Meneghetti et al., 2017): mental rotation and perspective taking accuracy correlated with the walking condition, and VSWM with both walking and describing the paths, though the regression model did not confirm their selective role. Rotation and perspective taking skills may influence mechanisms such as translating and shifting spatial perspective in situated navigation conditions (Wolbers & Hegarty, 2010), while they may be less involved in describing a path retrieved from memory (as suggested by the lack of correlation between the sMRT results and the shortest path describing condition). Our finding that visuospatial abilities had no clear role in predicting shortest path finding performance might be because the environment was already known, as visuospatial abilities are less involved in retrieval than in encoding (e.g., Pazzaglia et al., 2007). In the describing condition the lack of a clear involvement of visuospatial abilities may be due to the involvement of others, such as verbal abilities (Pazzaglia et al., 2007), that were not examined directly in the present paper. The role of individual factors as a function of retrieval condition and recall task deserves to be further examined.

As for wayfinding attitudes, sense of direction revealed a role in shortest path finding performance (in line with Muffato & Meneghetti, 2020), newly showing that this applied to both the walking and the describing conditions. Perceived sense of direction relates to environment knowledge with allocentric features (Sholl et al., 2006), and its role is detectable when environment recall is tested in a task stressing allocentric knowledge (as in finding a shortcut). Taken together, these results underscore the importance of considering multiple measures to thoroughly elucidate the individual factors - in terms of basic mechanisms (VSWM), higher-level visuospatial abilities (mental rotation and perspective taking) and wayfinding attitudes (Meneghetti et al., 2021) - that affect the retrieval of spatial knowledge about familiar environments.

Considering all these individual factors, the present study found that participants in a familiar environment identified the shortest path to a destination better when walking than when describing the path, in line with the findings of Hölscher et al. (2011). Walking a path, as opposed to traveling it mentally and describing it in words, might give access to visual information (landmarks and paths) useful for making ongoing adjustments. Performance in this condition may be associated with a greater activation of neural pathways involving the hippocampus, which has a functional role in the use of cognitive maps (Wolbers & Hegarty, 2010), although this needs to be investigated in future studies. Participants' written descriptions of the shortest paths nonetheless confirmed that people's mental representations have spatial proprieties (Denis, 2018), in familiar environments too (Meneghetti et al., 2017).

This study adds insight in the sphere of navigation skills and their implications. It shows that, when retrieving well-memorized spatial information - not encoding new environmental information, as is usually examined in the literature (Meneghetti et al., 2021) - a situated condition favors a more refined use of spatial knowledge (as when finding a shortcut, for instance; Weiner et al., 2009) than when describing a path from memory, even after accounting for individual factors. However, some limitations need to be mentioned, concerning: the lack of a post-test interview to see if respondents had indicated what they thought was the shortest path or simply the one they usually took; the paths (which offered a choice of routes but involved only two walking trials to avoid fatigue); and the buildings (chosen for their familiarity, but they could have other features that might affect path finding performance). Environmental factors, e.g. the alignment with salient environmental axes such as main roads, could also have influenced performance (as in Brunyè et al., 2015) and need to be better investigated in future studies.

To conclude, this study sheds light on the retrieval of spatial knowledge, in terms of finding the shortest path to a destination in a familiar environment. Performance is supported by individual factors, including how well we know the environment and our perceived sense of direction. After accounting for such individual factors, finding the shortest path is easier when walking it than when describing it in words.

Funding

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics

The study was approved by the Ethical Committee for Psychological Research at the University of Padova (No. 54DC637F57A65-BE0D1708333286D041D). All participants were informed about the purposes of the study and gave their written informed consent in accordance with the Declaration of Helsinki (World Medical Association, 2013).

Data availability statement

Data are available on Figshare. https://doi.org/10.6084/m9.figshare.13664339.

CRediT authorship contribution statement

Veronica Muffato: Formal analysis, Writing – original draft, Writing – review & editing. **Tommaso Feraco:** Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Laura Miola:** Writing – original draft, Writing – review & editing. **Carla Tortora:** Data curation. **Francesca Pazzaglia:** Writing – review & editing, Supervision. **Chiara Meneghetti:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of competing interest

None.

Acknowledgments

The present work was conducted as part of the *Dipartimenti di Eccellenza* research program (art.1, commi 314–337 legge 232/2016), supported by a grant from MIUR to the Department of General Psychology, University of Padua. Thanks go to Annachiara Castagna, Jacopo Dei Tos, and Alessandro Maraldo for collecting data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2021.101708.

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