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RESEARCH ARTICLE

How does environmental knowledge allow us to come back home?

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Abstract

Herein, we investigate how the three types of mental spatial representation (landmark, route and survey) are reorganized to perform wayfinding and homing behaviour. We also investigate the contribution of visuo-spatial working memory in reaching and in vista space in performing the retracing of the path. For this purpose, we asked 68 healthy college students to learn and come back along an unknown path in a real environment and to perform two different forward and backward working memory tasks, one in the reaching space (Corsi Block-Tapping Test) and the other in a vista space (Walking Corsi Test). The results show that participants performed better when travelling the route forward (which corresponds to the originally learned direction) than when travelling the route backward (return path) and that working memory in vista space is crucial for both wayfinding and homing behaviour, while the working memory for reaching space contributes only to homing behaviour. Although homing behaviour is an early mechanism in navigation shared among many species, it represents a very complex behaviour that requires both topographic and visuo-spatial memory as well as the first two levels of environmental knowledge.

Keywords Topographic memory · Spatial representation · Return path · Walking Corsi Test · Corsi Block-Tapping Test

Introduction

Finding our way in the world involves several cognitive processes, such as perceiving environmental information, creating and maintaining spatial representations in the short- and long-term memory, and using these representations during spatial navigation. Montello (2005) describes navigation as a "coordinate and goal-directed movement of one's self (one's body) through the environment" (p. 258). Moving through the environment may require various modes (crawling, walking, running, and driving a car) that differ in terms of degree of locomotion (active, the person controls his/her speed and heading, vs. passive, using means of transportation as a passenger). Different modes and degrees of locomotion determine how much environmental information people acquire and process (Montello 2005).

How environmental knowledge is acquired throughout life is still a matter of debate. In a seminal paper, Siegel and White (1975) describe three different types of mental environmental representations, namely, landmark, route, and survey representations. In landmark representation, individuals have a sort of figurative memory of environmental objects and they are able to beacon towards a salient landmark. In route representation, individuals build up a mental representation in which paths are connected to different landmarks through an egocentric perspective in which the individual's position allows to determine the relation between landmarks met along the path. Finally, in survey representation, individuals have a map-like representation regardless of their position, which implies the use of an allocentric perspective in which the mental environmental representation exists in spite of the individual's position. This last representation allows to reach a planned goal, to find novel paths and shortcuts when the familiar route is interrupted and to master a metric knowledge of the environment itself. In this model, the internal representations of the environment progress over time from the initial landmark stage to an ultimate stage of survey representation. Even if it is considered one of the

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most influential models of spatial knowledge acquisition, since the 1990s, other models have been advanced to explain how spatial knowledge is acquired (Tversky 1993; Montello 1998). Tversky (1993) proposes the existence of a further stage in which environmental representations are integrated with linguistic spatial categories due to the importance of language for human beings. Montello (1998) criticizes the rigid cumulative and hierarchical structure of Siegel and White's model, in which the acquisition of the lower stages is mandatory for the acquisition of higher level stages. In addition, he refuses the idea that metric knowledge takes so long to develop. Indeed, his studies suggest that also a minimal (in terms of seconds or minutes) exposure to a new environment may provide some metric configurational knowledge, which allows to return directly back to starting locations (Ishikawa and Montello 2006). Therefore, he proposed an alternative model named "Continuous Model" that strongly supports the idea of a continuous development of metric knowledge. According to the "Continuous Model", individuals will vary in the extent and accuracy of the spatial knowledge they acquire from direct experience. This variation has an important role in explaining the reason why people may be more or less proficient in integrating spatial information of separately learned places.

What determines proficiency in navigation is not readily understandable and is still a matter of debate in the scientific community. Several internal (i.e., personal attributes, gender, cognitive styles, and spatial strategies) and external (i.e., environmental attributes such as landmark differentiations; visual access to different parts of an environment from various points of view and layout complexity of the environment per se) factors have been found to affect navigational behaviour (e.g., Nori and Giusberti 2003, 2006; Nori et al. 2006; Nori and Piccardi 2011; Lawton 2001, 2010; Montello and Sas 2006; Thorndyke and Hayes-Roth 1982).

Concerning some internal factors, several studies have focused on gender differences in spatial navigation. Indeed, men have been found to be better at reading maps, estimating distances and mentally transforming environmental information compared to women (e.g., Lawton 2010). However, such differences may be modulated by other internal factors such as cognitive styles, familiarity with the environment, and preferred navigational strategies (e.g., Boccia et al. 2017; Lopez et al. 2018; Nori and Piccardi 2011).

A better understanding of how environmental knowledge is used to perform everyday life activities, such as moving through the environment to reach a destination and coming back home, is compelling. When our locomotion is goal-directed and requires a planned movement of the body around the environment in an efficient way we talk about wayfinding. Specifically, wayfinding requires a destination to reach, which is located beyond the local surround and involves problem-solving and decision-making skills (e.g., choosing routes to take; performing shortcuts; scheduling trips) (Montello 2005). On the other hand, coming back home (hereafter called homing behaviour) requires mechanisms underlying the dead reckoning, that is keeping track of one's own locomotion (both movement direction and rate of the movement) combined with a process of landmark recognition (Montello 2005).

Homing behaviour is the ability to return to the starting point (in most cases our home) and to do it in the easiest and fastest way. Retracing back a route requires retrieving the route previously travelled, recognizing a landmark associated with that place and selecting the right direction (Waller and Lippa 2007). This navigational process has been extensively investigated in animals: findings showed that some insects are able to use landmark-based navigation as well as other strategies when landmarks are unavailable (e.g., Collett and Collett 2000; Wehner 2003). These findings support the idea that a homing vector model of path integration exists, whereby a mental "navigator" tracks a trajectory back to home throughout the path (Fujita et al. 1990; Philbeck et al. 2001). Coming back to the starting point is an everyday task that requires specific strategies also for human beings (i.e., retrace strategy: Golledge 1995; path integration or look-back strategies: Montello 2005; Wiener et al. 2011). In humans, Wiener et al. (2011) found that the homing behaviour and not wayfinding is affected by age. Specifically, they observed deficits both in recognizing and in indicating the correct direction to follow when travelling back. Montello (2005) emphasized the use of the look-back strategy that requires "intentionally stopping, turning around, and memorizing the view behind you while traveling along a route" (p. 270). The ability to retrace a path is crucial, especially in unfamiliar environments, because it allows to navigate in a just explored path, from the end to the start, coming back in a recently learnt part of the environment (Miller and Eilam 2011). In general, humans use landmarks (salient objects or buildings met along the route in an egocentric perspective; Lynch 1960; Caduff and Timpf 2008), because they can be associated with a specific direction (Denis et al. 2014; Piccardi 2009; Nico et al. 2008); however, in a following stage of environmental knowledge acquisition, they are able to build up a map in which landmarks are placed regardless of their relative positions, namely, in an allocentric perspective. Karimpur et al. (2016) performed three well-designed experiments in a virtual environment (i.e., a simple blocks world maze) to investigate three different problems that people met during wayfinding. Specifically, the authors focused on perspective taking, return path and landmark position. In detail, in the first experiment, they asked subjects to learn a route of eight intersections through successively shown pictures of each of the intersections. Then, subjects had to find the same path again (wayfinding), either in the forward (from starting point to destination) or in the backward direction (from destination to starting point). They found that participants were faster and better when travelling the route forward than backward. In the second experiment, the authors asked some subjects to learn a path through a map, and other subjects to learn through a verbal description. Five minutes later, the learned path was shown as a video in reverse order through the virtual maze. The video stopped at every intersection and the subjects had to indicate the correct path directions. The results showed that there were no differences related to the learning condition (map vs. verbal description) and that landmarks are useful to find the return path in accordance with their position assumed during the forward path. In subsequent experiments, the authors asked subjects to memorize the path in a map view or in an egocentric perspective, attempting to memorize at least one landmark and the associated turning direction. Then, some subjects had to learn the path forward and provide the verbal description and others had to learn the path and provide the verbal description of the return path. These last series of experiments demonstrate that the encoding direction is crucial when there is an optimal landmark position, placing in discussion the importance of the invariance of landmark position and leaving an open debate and the need for other well-designed experiments to further investigate the contribution of these factors in wayfinding and homing behaviour.

In the present study, we aimed to investigate how the format (landmark, route, and survey) of acquired environmental representation is organized to perform the homing behaviour. Furthermore, we were interested in better understanding the contribution of visuo-spatial working memory in performing the retracing of the path, in reaching and vista space—namely, the space we can see from a single location or with only little exploratory movements, such as single rooms or town squares (Wolbers and Wiener 2014). For this purpose, we asked a group of healthy young subjects to learn and come back along an unknown path in a real environment and to perform two different working memory tasks, one in the reaching space and the other in a vista space, hypothesizing that only the working memory for the vista space would predict performances on path retracing. As a corollary aim, we investigated whether gender may affect performance in wayfinding and homing behaviour.

Materials and methods

Participants

Sixty-eight college students of L'Aquila University (26 males and 42 females; mean age: 24.06 ± 3.36) were recruited. Before participating in the study, the subjects underwent an informal interview to exclude the presence of any previous/current neurological or psychiatric disorders as well as abuse of substances or addiction. We used the Familiarity and Spatial Cognitive Style Scale (FSCS; Piccardi et al. 2011a; Italian version: Nori and Piccardi 2012) to exclude any individuals that suffered from navigational disorders. None of the participants reported navigational deficits or developmental topographic disorientation (Iaria et al. 2005, 2009; Bianchini et al. 2010). According to the tenets of the latest Declaration of Helsinki, before the assessment and after a full explanation of the protocol and of the non-invasiveness of the study, a written informed consent was obtained from each participant. The Ethics Committee of L'Aquila University approved the study.

Method

The following tests were administered to all participants.

Visuo-spatial memory in reaching space

- *The Corsi Block-Tapping Test* (CBT: Corsi 1972; Piccardi et al. 2013; Palmiero et al. 2016) is composed of nine wooden blocks (3 × 3 cm) fixed on a board (30 × 25 cm) in a scattered array (see Fig. 1a). It allows to assess memory in the reaching space, which refers to the portion of space within "grasping distance" (Halligan and Marshall 1991). The examiner taps a number of blocks at a rate of one block per 2 s; the participant is asked to tap the block in the same order immediately afterwards. The number of blocks to be tapped gradually increases in length (i.e., until a nine-block sequence). The task was administered both forward (fCBT) and backward (bCBT) (tapping the sequence of blocks in reverse order). Both for fCBT and bCBT five sequences were used for each length: if the participant correctly reproduces at least three out of five sequences, the test continues with the next length; otherwise, it is stopped. The score corresponds to the number of blocks correctly tapped in the longest sequence (block span).

Visuo-spatial memory in navigational vista space

- *The Walking Corsi Test* (WalCT: Piccardi et al. 2008, 2013; Palmiero et al. 2016) is a large-scale version of the CBT and it measures the memory of short paths in the navigational vista space, which, according to Wolbers and Wiener (2014), corresponds to the portion of the navigational space that can be experienced from a single location or with only little exploratory movements. Nine black squares (30 × 30 cm) were placed on the floor within a 3 × 2.5 m. layout (1:10 scale of CBT), together with a starting point located outside the layout (see Fig. 1b). The experimental conditions (forward fWalCT and backward bWalCT) and scoring procedures

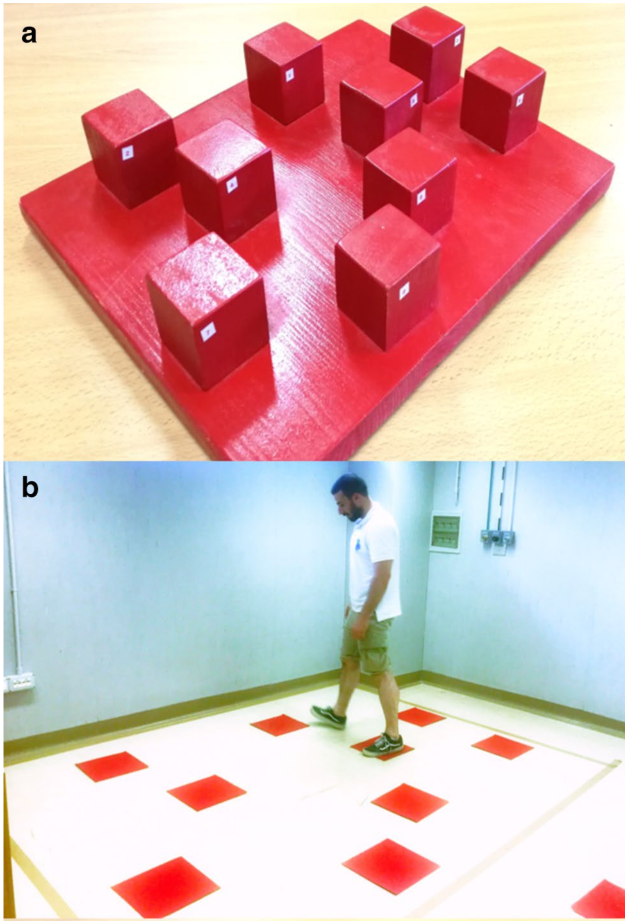

Fig. 1 Navigational vista and reaching space. Assessment of working memory in the reaching and in the vista space. **a** Corsi Block-Tapping test used to assess working memory in the reaching space. **b** Walking Corsi test used to assess working memory in the vista space. Written informed consent was obtained from the subject represented in the figure for publication of this experiment. A copy of the written consent is available for review by the Editor-in-Chief of this journal

were the same as those described above for the CBT, with the exception of the starting position, which was identical both for the examiner and for the participant. As in the CBT, the number of squares to be reproduced gradually increases in length (from a 2-square sequence to a 9-square sequence). Participants were required to reproduce the square sequences shown by the examiner by actually stepping on the black squares. The score is the number of squares in the longest sequence correctly reproduced (square span).

The CBT and WalCT forward sequences were derived from Piccardi et al. (2008, 2013); the backward conditions of both tasks were modified from Palmiero et al. (2015, 2016) following the procedure used by Piccardi et al. (2013). To avoid a learning effect, the CBT and WalCT sequences were not the same in the two tasks, but they were matched for difficulty; the administration order of the two tasks was counterbalanced across subjects.

Navigational skills in an ecological environment

Due to the nature of the experimental requirements (see detailed description below), navigational tasks performed in the real environment were administered in the following order: route learning, landmark recognition, and landmark positioning on the map. The forward- and backward paths were counterbalanced across subjects to avoid effects due to the path.

- *Route navigation (Route Representation)* To test navigational skills in the real world, we asked participants to learn two indoor paths within the Department of Biotechnological and Applied Clinical Science in L'Aquila University (Fig. 2a). These paths were similar: they were well lit, had a comparable number of well-visible landmarks along them, and had the same length (120 m). The first path included 7 straight, 3 left, and 3 right turns on the third floor. Similarly, the second path included 7 straight, 3 left and 3 right turns on the ground floor.

  The examiner showed one of the paths to the subject, telling him/her to pay attention, because he/she would have to reproduce it at the end of the demonstration. In the forward-path condition, blindfolded participants came back with the examiner to the beginning of the path following another route and were then asked to perform the path without the guidance of the examiner. Conversely, in the backward-path, once they had arrived at the end of the path, participants were required to come back to the starting point without the experimenter's guidance, performing exactly the same route as previously walked. The experimenter always followed the subject, keeping a few steps behind to avoid providing directions. For each participant and path, the number of correct turns was collected (maximum score: 6). At the end of each path (i.e., forward- and backward paths), participants performed the landmark recognition task (see below); they were then required to locate them on a blank map of the path (see below).
- *Landmark recognition (Landmark Representation)* At the end of each path (i.e., forward- and backward paths), participants were asked to recognize the landmarks ($n = 4$) encountered along the path (e.g., an elevator and a cabinet) from among distractors (e.g., a similar elevator to the actual landmark, $n = 4$) (Fig. 2b). For each participant and path, the number of landmarks correctly identified was collected (maximum score: 4).
- *Landmark location (Survey Representation)* To evaluate the map-like representation (allocentric representation), participants were asked to place the landmarks met dur-

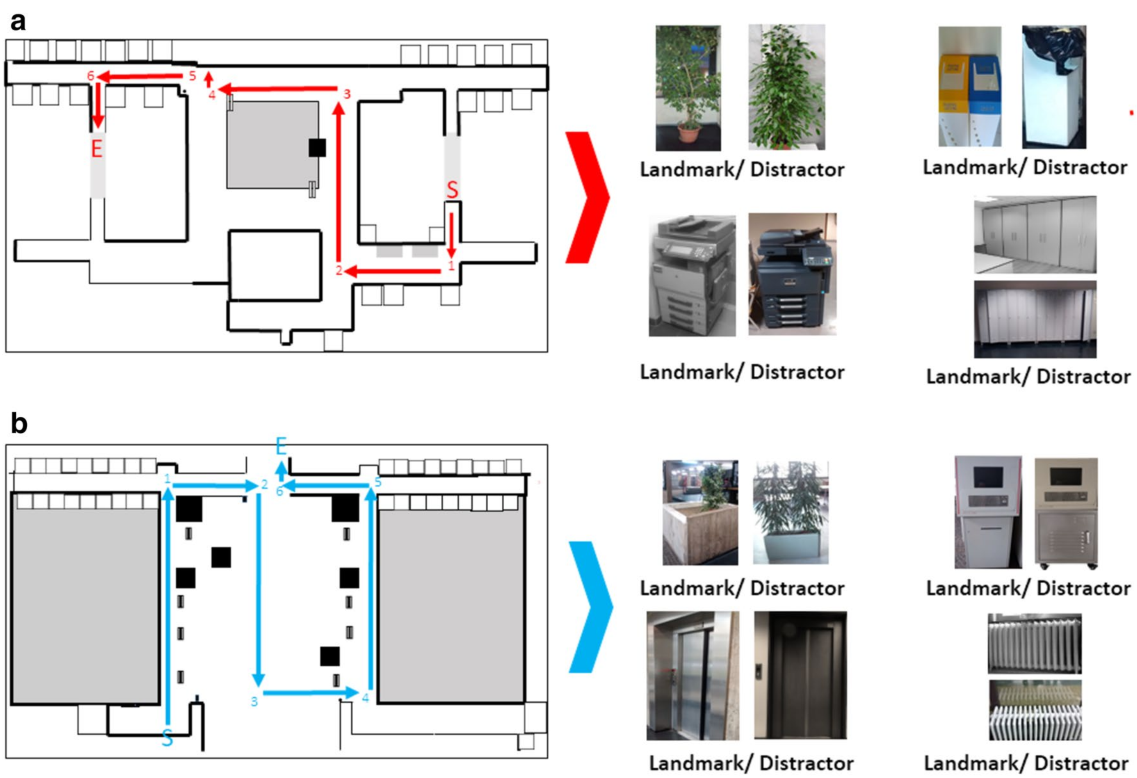

Fig. 2 Navigation in real environment. Assessment of navigational skills in ecological environment. **a** First indoor path within the L'Aquila University (third floor) used to assess route learning skills. Turns are numbered (1–6) whereas start and ending points are labelled as letters (S–E). On the right, examples of landmarks encountered along the path and their distractor are shown. **b** Second indoor path within the L'Aquila University (ground floor) used to assess route learning skill. Turns are numbered (1–6), whereas start and ending points are labelled as letters (S–E). On the right, examples of landmarks encountered along the path and their distractor are shown

ing both the forward- and backward paths on the blank map. For each participant and path, the number of correct positions was collected (maximum score: 4).

Statistical analysis and results

As a preliminary step of our statistical analysis, we computed the proportion of accuracy in the tapping tasks on the landmark, route, and survey representation of each path (forward vs. backward retrievals). Next, we performed a 2 (condition: forward vs. backward) × 3 (representation: landmark vs. route vs. survey) repeated measures ANOVA. We found a main effect of Condition ($F_{1,67}=4.91$; $p=0.03$; $\eta_p^2=0.07$; observed power = 0.59), with better performances on forward condition (Fig. 3). We also found a main effect of Representation ($F_{2,134}=65.23$; $p<0.001$; $\eta_p^2=0.493$; Observed power = 1.00); post hoc pairwise comparisons showed that performances on landmark ($p<0.001$, Bonferroni's correction for multiple comparisons) and route representations ($p<0.001$, Bonferroni's correction for multiple comparisons) were higher than those observed on survey representation (Fig. 3).

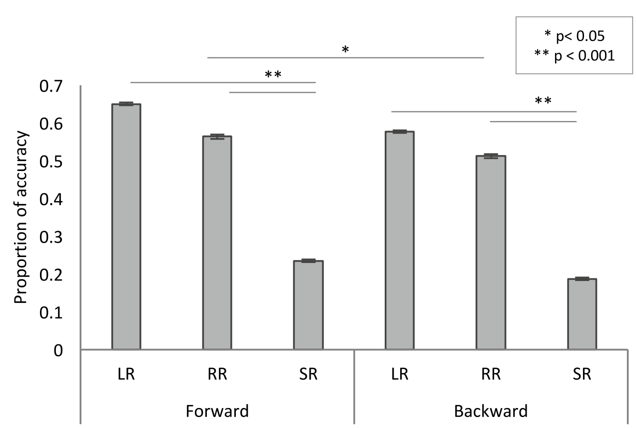

Fig. 3 Navigational skills in real environment from wayfinding and homing behaviour. Mean and standard error of proportion of accuracy on landmark (LR), route (RR), and survey (SR) representations, in forward and backward modalities

We then explored whether performances on the ecological navigational tasks were significantly associated with performances on the laboratory assessment of topographic memory achieved using WalCT and CBT, in both forward (fWalCT and fCBT) and backward (bWalCT and bCBT) conditions. Pearson correlation coefficients (and relative one-tailed p_s for positive correlation) are reported in Table 1. We found that *forward retrieval of Route representation* was significantly correlated with both fWalCT and bWalCT. In addition, *backward retrieval of Route representation* was significantly correlated with both fWalCT and bWalCT, as well as with fCBT.

To further disentangle whether performances on path retracing was selectively predicted by memory for positions within vista space, we performed a linear regression analysis with performances on bWalCT and bCBT as predictors and *backward retrieval of Route representation* as dependent variable. We found that retrieval was significantly predicted by bWalCT (Beta = 0.263; t = 2.040; p = 0.045), but not bCBT (Beta = 0.079; t = 0.615; p = 0.541). No significant effects were detected for the *forward retrieval of Route representation* (fWalCT: Beta = 0.216, t = 1.747, p = 0.085; fCBT: Beta = 0. 042, t = 0.340, p = 0.735).

Finally, based on the previous findings on gender differences, which were found to affect topographic memory (Piccardi et al. 2008, 2013, 2014), we explored whether performance on CBT and WalCT in forward and backward modalities was differently affected by gender. Thus, using gender as a model, we aimed to provide evidence for a dissociated system for homing behaviour. Thus, we performed a 2 (*group:* women vs. men) × 2 (*Space*: WalCT vs. CBT) × 2 (*condition*: forward vs. backward) ANOVA on the number of squares/cubes correctly retrieved. We detected a main effect of condition ($F_{1,66}$ = 4.27; p = 0.04; η_p^2 = 0.06; observed

Table 1 Pearson correlation coefficients

	FCBT	BCBT	FWalCT	BWalCT	FRoute	FLandmark	FSurvey	BRoute	BLandmark	BSurvey
fCBT										
r	1	0.314**	0.222*	0.292**	0.090	0.003	−0.021	0.265*	−.307**	0.056
p		0.005	0.034	0.008	0.232	0.490	0.433	0.015	0.005	0.326
bCBT										
r	0.314**	1	0.413**	0.403**	0.095	0.100	−0.002	0.185	−0.007	0.094
p	0.005		0.000	0.000	0.221	0.208	0.494	0.065	0.478	0.222
fWalCT										
r	0.222*	0.413**	1	0.500**	0.226*	−0.040	−0.148	0.416**	−0.097	0.022
p	0.034	0.000		0.000	0.032	0.374	0.114	0.000	0.215	0.430
bWalCT										
r	0.292**	0.403**	0.500**	1	0.376**	−0.092	0.044	0.295**	−0.041	0.158
p	0.008	0.000	0.000		0.001	0.229	0.362	0.007	0.371	0.099
fRoute										
r	0.090	0.095	0.226*	0.376**	1	−0.079	0.252*	0.363**	0.080	0.208*
p	0.232	0.221	0.032	0.001		0.261	0.019	0.001	0.257	0.044
fLandmark										
r	0.003	0.100	−0.040	−0.092	−0.079	1	0.022	0.020	−.248*	−0.136
p	0.490	0.208	0.374	0.229	0.261		0.430	0.436	0.021	0.135
fSurvey										
r	−0.021	−0.002	−0.148	0.044	0.252*	0.022	1	0.128	0.054	0.392**
p	0.433	0.494	0.114	0.362	0.019	0.430		0.148	0.331	0.000
bRoute										
r	0.265*	0.185	0.416**	0.295**	0.363**	0.020	0.128	1	−0.105	0.228*
p	0.015	0.065	0.000	0.007	0.001	0.436	0.148		0.197	0.031
bLandmark										
r	−.307	−0.007	−0.097	−0.041	0.080	−.248	0.054	−0.105	1	0.205*
p	0.005	0.478	0.215	0.371	0.257	0.021	0.331	0.197		0.046
bSurvey										
r	0.056	0.094	0.022	0.158	0.208*	−0.136	0.392**	0.228*	0.205*	1
p	0.326	0.222	0.430	0.099	0.044	0.135	0.000	0.031	0.046	

p (one-tail) < 0.01 (**) or 0.05 (*)

power = 0.53), with better performances on forward condition (Fig. 4). In addition, we found a main effect of gender ($F_{1,66}$ = 9.75; p = 0.003; η_p^2 = 0.13; observed power = 0.87), with men performing better than women (Fig. 4). Interestingly, we found a significant gender-by-space-by-condition interaction ($F_{1,66}$ = 4.55; p = 0.04; η_p^2 = 0.06; observed power = 0.56): post hoc pairwise comparisons showed that women performed significantly worse on WalCT as compared with CBT in forward condition (p = 0.003, Bonferroni's correction for multiple comparisons) (Fig. 4).

Discussion

In this study, we aimed to investigate the contribution of the format (landmark, route, and survey) of environmental knowledge on the homing behaviour, an everyday life activity poorly investigated but crucial in successful navigation in novel environments. Furthermore, we investigated the role of visuo-spatial working memory on reaching and navigational vista space as well as the possible presence of gender differences. Summing up, we found that travelling the route forward (i.e., wayfinding) was easier than travelling the route backward (i.e., homing behaviour). The survey format is the most difficult to be acquired in both conditions, namely, wayfinding and homing behaviour. Working memory in vista space is crucial for both wayfinding and homing behaviour, while the working memory for reaching space contributes only to homing behaviour. Indeed, only topographic and not visuo-spatial working memory predicts performance on homing behaviour.

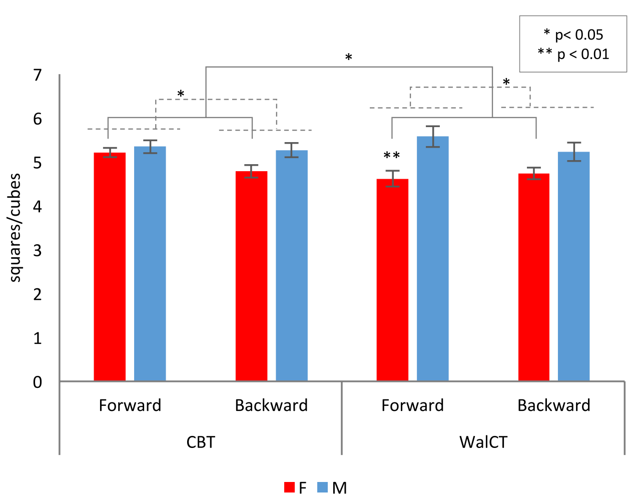

Fig. 4 Working memory in navigational vista and in reaching space. Mean and standard error of proportion of accuracy on WalCT and CBT, in Forward and Backward modalities, for males (M) and females (F)

According to Kitchin and Blades (2001), individuals adopt two main strategies for learning and retracing a route. The first is based on landmark knowledge: people may encode a turn in relation to a specific landmark; the second is based on knowledge of directions: individuals learn a sequence of turns. More recently, Karimpur and Hamburger (2016) highlighted the importance of integrating the other modalities besides vision during wayfinding, describing a congruency effect in the landmark recognition phase. They also found that self-reported strategies (people who prefer orienteering through landmarks: object learners vs. people who prefer to memorize direction sequences during navigation: route learners) should be considered in landmark-based wayfinding experiments, because they affect the encoding of environmental information.

Currently, the two strategies individuated by Kitchin and Blades (2001) could correspond to individual preferred spatial strategies. These two strategies (landmark knowledge and knowledge of direction) roughly correspond to the *Landmark* and *Route Representation* of the environment (Siegel and White 1975; Montello 1998). Our findings show that subjects were better when travelling the route forward (which corresponds to the originally learned direction) than when travelling the route backward (homing behaviour). This result is in line with findings coming from other studies both in real and virtual environments (Karimpur et al. 2016; Gillner and Mallot 1998; Wiener et al. 2012; Mora et al. 2014). Our data showed that participants were able to recognize landmarks met along the path and to travel the route forward and backward; however, very few participants were able to place landmarks on the blank map of the path, suggesting that survey knowledge was not necessarily yet achieved. This result ties well with the idea that also a quick exposure to a new environment may allow for the acquisition of some metric and configurational knowledge, which allows to return directly back to the starting location (Ishikawa and Montello 2006). These results are also in line with literature reporting that only some individuals develop higher levels of environmental knowledge (i.e., survey representation), which are known to be associated with better skills in mental rotation and perspective taking (e.g., Verde et al. 2018; Piccardi et al. 2017; Pazzaglia and De Beni 2006).

Furthermore, we found an interesting relation between working memory in the reaching space and travelling route backward and working memory in the vista space and travelling the route both forward and backward, which suggests different mechanisms underlying wayfinding and homing behaviour. The scientific literature is full of contributions demonstrating a crucial role of visuo-spatial working memory in wayfinding (e.g., Piccardi and Nori 2011; Garden et al. 2002; Lindberg and Gärling 1981; Meilinger 2008; Meilinger and Knauff 2008; Meilinger et al. 2008). Indeed, already Lindberg and Gärling (1981) found that working memory was required to give directions and estimate distances. In this study, participants were asked to walk through alleyways and estimate the direction and the distance to a reference point, while they were performing a concurrent task; the result of the study showed a difficulty in keeping track of the reference points. However, participants were still able to encode information about the route (i.e., distance and direction). The authors conclude that working memory contributes to handling spatial navigation tasks. Then, Garden et al. (2002) found that individuals with high spatial ability were more affected by a spatial concurrent task (i.e., spatial tapping task on a keypad comprising a matrix of 3 × 3 squares), whereas individuals with low spatial ability were more affected by a verbal concurrent task (i.e., articulatory suppression). These results suggest that individuals' internal factors, such as gender, personality traits, cognitive styles, and verbal and visuo-spatial skills, affect the strategies individuals adopt to perform the navigational task. In addition, Meilinger et al. (2008) found that wayfinding skill was affected by both verbal and spatial interference. Accordingly, in Nori et al. (2009), individuals with high visuo-spatial working memory performed better than individuals with low visuo-spatial working memory in a wayfinding task: people with high visuo-spatial working memory compare their spatial mental representation directly with the external environment, promoting the online updating of spatial information. Indeed, walking through an environment entails continuous updating of perspective. The authors also found that the moving reference frame would constitute an additional load for the spatial component of visuo-spatial working memory, which individuals with low visuo-spatial working memory are unable to represent.

The results of the present study demonstrate a different contribution of working memory related to the portion of the space. Indeed, we found that the homing behaviour is selectively predicted by the topographic working memory and not by the visuo-spatial one. It should not be forgotten that the space around us is a multifactorial construct and that distinct brain areas are responsible for coding different portions of the space (Nemmi et al. 2013). From a behavioural point of view, the space may be defined as outside reaching distance (far space), as within reaching distance (near space), and as body surface (bodily space) spaces (Berti and Frassinetti 2000; Rizzolatti et al. 2000). The coding of space as near and far is not only determined by arm-reaching distance, but is also dependent on how the brain represents the extension of the body space. Near space, also called reaching space, refers to the portion of space within 'grasping distance' (i.e., the space in which a seated individual can grasp an object), whereas far space, also called navigational space (De Nigris et al. 2013), extends beyond our reaching space and has been called the space within 'walking distance' (Halligan and Marshall 1991). More recently, Wolbers and Wiener (2014) suggested the existence of a vista space (i.e., the space you can see from a single location or with only little exploratory movements) that could be smaller than the environmental space (i.e., the space beyond the "vista space", which could be represented after integrating multiple views acquired during actual navigation).

Here, we found not only that reaching and vista spaces are different, but also that working memory, measured in reaching and in vista space, may contribute in a different way to navigational tasks in a real environment. As in the studies mentioned above, the working memory for the reaching space has a role in connecting the landmarks met along a path to provide information for homing behaviour; working memory for the vista space is always required both in wayfinding and in the homing behaviour, suggesting a more active role in all navigational tasks that goes beyond the simple mechanism to keep in mind visuo-spatial cues.

Studies about homing behaviour show that this everyday life activity requires different cognitive resources with respect to other navigational tasks and individuals do not perform the same route to come back if free to choose the return path. In this vein, Mora et al. (2014) observed the homing behaviour of 500 individuals, finding that most of them got lost when they had to come back to their own cars. In fact, our data demonstrate that only homing behaviour requires both vista and reaching space-working memory.

Moreover, while forward working memory for vista space is associated with performances in the forward path, only forward and backward working memory for vista space and forward working memory for reaching space are associated with performances in the backward path, suggesting that only in the homing behaviour, in addition to the working memory for the vista space, individuals also need to manage online the reaching space information, maybe because they have to visualize a figurative representation of the environment, namely, a map. Furthermore, we found that backward working memory for vista space significantly predicts homing behaviour, assessed using path retracing. This result suggests that bWalCT may be used as a tool to assess homing behaviour.

Even though corollary, the present study suggested that men and women performed the working memory tasks in reaching and in navigational vista space in a different way. For both sexes forward tasks are easier, but only women performed significantly worse on WalCT as compared with CBT in forward condition. The backward condition, instead, is harder for both men and women, further suggesting the contribution of other internal factors (e.g., the cognitive styles), which should be directly tested in future studies. Another explanation may be attributed to the homing behaviour per se. Indeed, homing behaviour is an early mechanism that human beings share with other species (Golledge 1995). As demonstrated for other early mechanisms, such as path integration, the system that allows to update one's own position in the environment by processing idiothetic information and geometric environmental shape (Wang and Spelke 2000), gender differences did not emerge (e.g., Piccardi et al. 2009, 2011b). We may speculate that homing behaviour, similar to path integration, has evolved similarly in men and women; our result is also in line with previous results, for example, Prestponik and Roskos-Ewoldsen (2000), who did not find gender differences in the time spent for retracing a previously travelled route. However, the small number of participants and an imbalance between men and women in our sample did not allow us to draw any definite conclusions about the absence of gender effects in homing behaviour.

In conclusion, the present results suggest that homing behaviour on unfamiliar paths requires a backward reconstruction of the route that is more difficult than wayfinding on the same paths. Interestingly, visuo-spatial working memory for vista space strongly contributes to wayfinding and homing behaviour, supporting the idea that visuo-spatial working memory in the reaching space may be predictive solely for keeping in mind the environmental knowledge when the task is harder.

Compliance with ethical standards

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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