Psychological Research (2019) 83:1836–1850
https://doi.org/10.1007/s00426-018-1033-4

ORIGINAL ARTICLE

Spatial mental representations: the influence of age on route learning from maps and navigation

Veronica Muffato[1,2] · Chiara Meneghetti[1] · Rossana De Beni[1]

Received: 31 October 2017 / Accepted: 27 May 2018 / Published online: 30 May 2018

Abstract

Experiencing an environment by navigating in it or reading a map (route and survey views, respectively) is a typical activity of everyday life. Previous research has demonstrated that aging coincides with a decline in spatial learning, but it is unclear whether this depends to some degree on how the learning conditions relate to the method used to assess the recall. The present study aims to shed light on this issue. Forty-six young, 43 young-old and 38 old-old adults learned outdoor environments from a map and a video, then performed sketch map and route repetition tasks. Participants were assessed on their visuo-spatial working memory (VSWM), and reported their self-assessed visuo-spatial inclinations. The results showed that young adults completed the sketch maps more accurately after learning from a map rather than a video. The same was true of the young-old participants (but not of the old-old), though their performance was not as good as the younger group's. The learning condition had no effect on the route repetition task, however, and only age-related differences emerged, with both older groups performing less well than the young adults. After controlling for learning condition and age group, VSWM and participants' reported propensity to explore places predicted their accuracy in both types of spatial task. The overall results, discussed in the light of spatial cognitive and aging models, show that learning condition (combined with recall tasks) and visuo-spatial factors influence spatial representations, even in aging.

Introduction

Spatial learning from maps and navigation

When people experience a new environment, they form an internal mental representation of the spatial information (also called a cognitive map, Tolman, 1948), in which the layout of the environment, and the spatial relationships between landmarks can be inferred from any perspective (Wolbers & Hegarty, 2010). Different methods can be used to learn and mentally represent spatial information, such as map reading and navigating. Maps depict whole areas, showing landmarks and paths connecting them, based on an aerial view of the layout, so they present spatial information allocentrically. This input modality can be described as taking a survey perspective to present information (Richardson, Montello, & Hegarty, 1999; Thorndyke & Hayes-Roth, 1982; Richardson et al., 1999; Thorndyke & Hayes-Roth, 1982). Navigating in an environment, on the other hand, presents landmarks as seen in the first person, i.e., from the so-called route perspective (Richardson et al., 1999). We can navigate in real life, or simulate this experience using visual media, such as slides, videos or virtual environments. Visual media are frequently adopted as a useful approximation of real-world learning in a more controlled setting (Moffat, 2009; Richardson et al., 1999). They prompt spatial mental representations that are not exactly the same as those deriving from real navigation (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Mellet, Laou, Petit, Zago, Mazoyer, & Tzourio-Mazoyer, 2010) because real navigation involves vestibular sense, proprioception and optic flows, which may influence the formation of a mental representation. There is another distinction worth mentioning when learning an environment from a route perspective, by freely exploring an environment or following a given path (i.e., in a more active and passive modality, respectively): both can generate a spatial representation, but their features may differ to some extent, and they are used differently depending on the research aims (e.g., Nadel, 2013).

✉ Veronica Muffato
veronica.muffato@gmail.com

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

[2] Department of Psychological, Health and Territorial Sciences, University of Chieti, Chieti, Italy

Several studies have examined environment learning by exploring it visually from a survey (map) or route (real or virtual navigation) perspective, and shown that perspective influences our mental representations (Waller & Nadel, 2013). One of the aspects influencing the more survey- or route-based features of these representations is the type of recall task administered (e.g., Boccia, Guariglia, Sabatini, & Nemmi, 2016; Colombo et al., 2017; Lee & Tversky, 2001; Richardson et al., 1999; Shelton & McNamara, 2004; Taylor, Naylor, & Chechile, 1999; Taylor & Tversky, 1992; Thorndyke & Hayes-Roth, 1982; Zhang, Zherdeva, & Ekstrom, 2014). Numerous types of spatial recall task can be used to capture the features of a mental representation. Some can prompt the recall of spatial information based on allocentric knowledge, such as when drawing a map from memory, and reproducing the landmarks located in the area (as in a sketch map completion task) (Blades, 1990; Rovine & Weisman, 1989). Some demand an egocentric point of view, if they involve repeating or retracing a previously taken path, for instance (as in tasks assessing the ability to recall a succession of turns and landmark positions). Other tasks examine the ability to find the best way to reach a destination (i.e., finding shortcuts, for instance), which demands an egocentric view, and such tasks assess allocentric knowledge in terms of the ability to link locations not explored directly. As a consequence, some studies have reported different effects on spatial mental representations that depended on the type of input used (e.g., map reading or navigating), and the type of recall task administered (eliciting knowledge from a survey or route perspective). The issue has yet to be explored systematically.

Some researchers found evidence to indicate that mental representations have features similar to the input used (from a survey as opposed to a route perspective) when recall tasks elicit the use of the same perspective as in the encoding phase. For instance, Taylor et al. (1999) asked participants to study a map or learn from navigating an environment, giving them a goal that prompted the use of a survey perspective (to learn the layout), or a route perspective (to learn the fastest way to a location). Spatial memory was tested with pairs of tasks (that involved estimating distances, describing paths, etc.), in which one task necessitated the use of a route perspective (e.g., describing the path to take from one landmark to another), and the other the survey perspective (e.g., standing at a given point and describing what lies in a given direction behind a wall). Their results indicated that people who studied maps with a survey-focused goal performed more accurately in tasks demanding a survey perspective, while those navigating with a route-focused goal were more accurate in tasks demanding a route perspective. Similarly, Shelton and McNamara (2004) found that perspective influenced encoding and retrieval in a series of experiments that involved asking people to learn environments from descriptions or videos (and thus from route and survey perspectives), and then complete a scene recognition task using route-based and survey-based images.

On the other hand, some evidence suggests that accessing a different perspective from the one used to learn the input enables people to form mental representations capable of incorporating multiple views (Taylor & Tversky, 1992; Zhang et al., 2014). Zhang et al. (2014) asked people to gain extensive experience (with five learning blocks) of different environments by map reading or navigating, and then complete tasks that involved making spatial inferences. One task specifically required allocentric knowledge, while the other demanded egocentric knowledge. The authors found a different degree of improvement in spatial performance with practice for the two types of recall task as a function of the learning condition. After learning from maps, there was a comparable improvement over the learning blocks for the two (allocentrically- and egocentrically-based) tasks. After learning by navigating, however, participants improved faster in the egocentric than in the allocentric task.

The above studies go to show that different learning modalities have different effects on the dynamics of how tasks demanding allocentric or egocentric knowledge are performed. Learning from a survey perspective (using maps) gives more immediate access to allocentric knowledge, while learning from a route perspective relies more on viewpoint- or orientation-specific knowledge (Shelton & McNamara, 2004; Taylor et al., 1999). After sufficient exposure to an environment, however, the two types of learning input are generally comparable, as seen in the case of participants accessing route-based views after learning from maps (Zhang et al., 2014). This shows that individuals are able to mentally switch viewpoints (from a survey to a route perspective and vice versa; e.g., Shelton & McNamara, 2004), subject to individual differences. Some people may be more able than others to switch between egocentric (e.g., repeating a previously explored path) and allocentric (e.g., identifying shortcuts) strategies (e.g., Iglói, Zaoui, Berthoz, & Rondi-Reig, 2009; Wiener & Mallot, 2003).

To sum up, the learning condition and the type of recall task used to assess spatial knowledge can modulate the formation and use of spatial mental representations. Individual differences can influence the quality of spatial mental representations too. Such differences include aging, which may have a particular influence on the features of spatial representations, i.e., the degree to which they depend on the learning modalities and recall tasks involved.

Spatial learning from maps and navigation in aging

The features of spatial representations with aging, and especially their flexibility in shifting from one perspective to another, are a matter of growing interest to researchers, because our spatial learning ability declines as we grow older. This applies not only to pathological aging (Gazova et al., 2013), but also to normally-aging individuals (Klencklen, Després, & Dufour, 2012; Lithfous, Dufour, & Després, 2013). In particular, research has demonstrated that mentally switching viewpoints becomes more difficult with aging, especially when navigating and then switching from an egocentric to an allocentric modality to complete a spatial recall task (e.g., Devlin & Wilson, 2010; Harris, Wiener, & Wolbers, 2012). Aging-related spatial representation difficulties can be revealed by analyzing the type of input (map reading and navigating) vis-à-vis the spatial recall modalities used (focusing more on egocentric or allocentric knowledge). As concerns learning from a map, when the resulting mental representation was tested with a task that retained the same configurational properties (such as a sketch map task), some researchers found few or no age-related differences (Muffato, Meneghetti, Di Ruocco, & De Beni, 2017; Yamamoto & DeGirolamo, 2012). This was presumably attributable to the consistency between the input and recall modalities. Age-related differences after learning from a map emerged more clearly when the spatial recall tasks involved adjusting to a different type of request with a more egocentric focus, such as having to imagine adopting imaginary views (Borella, Meneghetti, Muffato, & De Beni, 2015), or choosing the quickest way to reach a goal (Salthouse & Siedlecki, 2007). Some studies have shown that aging affects the ability to learn spatial information by navigating (using both real and visual media; Klencklen et al., 2012; Moffat, 2009); for instance, older adults (especially those in their seventies) generally had more difficulty with re-walking a previously-learned route (route repetition task; e.g., Barrash, 1994; Muffato, Meneghetti, & De Beni, 2016; Wilkniss et al., 1997). There were some exceptions, however: no age-related differences emerged, for instance, in participants' ability to find their way in a maze once they had learned the route perfectly (Jansen, Schmelter, & Heil, 2010). Age-related differences do emerge clearly in tasks that involve managing spatial knowledge (Cushman, Stein, & Duffy, 2008), such as recalling information allocentrically (with map drawing tasks; Muffato et al., 2016), after learning it by navigating. There have been reports of older adults being impaired in an allocentrically-based location task, not only after navigating in an environment (e.g., Meneghetti, Borella, Carbone, Martinelli, & De Beni, 2016), but also after route learning in general, such as from spatial descriptions (e.g., Meneghetti, Borella, Gyselinck, & De Beni, 2012). The more marked age-related differences identified in the above studies can be attributed to the switch between the learning format (from a route perspective) and the test format (with an allocentric focus).

The trouble that older adults have with managing several spatial demands after learning from a route perspective (while their difficulty is less accentuated with input from a survey perspective) is also evident when two learning inputs are compared directly. Yamamoto and DeGirolamo (2012) asked participants to learn the locations of landmarks by looking at an aerial view (a map) and by navigating in the environment, and then to locate the landmarks on a sketch map. They found that older adults sketched the environment less accurately than younger people after navigating, while the two age groups' performance was the same after studying the aerial view, suggesting that the ability to learn from a map is better preserved with aging than exploratory navigation skills. The authors discussed their findings in relation to neuroimaging evidence of the medial temporal lobe—implicated in navigation, but not in map reading—being susceptible to age-related decline (Yamamoto & DeGirolamo, 2012), and making it more difficult to acquire information egocentrically than allocentrically. The value of their results is limited, however, by the fact that participants' recall of the environment was only tested with the sketch map task, which retained the same format as learning from an aerial view. The case of learning by navigating and then completing a task assessing route-focused knowledge was overlooked. How the relationship between learning inputs and spatial recall tasks is influenced by aging remains an open issue.

In short, studies on aging have produced some preliminary evidence of differences in older adults' ability to learn from maps vis-à-vis navigating, with some diversity relating to whether or not the recall modality is consistent with the learning modality. Age-related decline is more severe when a change of perspective between the learning and the testing stages is required. The findings published to date are insufficient, however, since few comparisons have been drawn in the elderly between learning from maps and by navigating (Yamamoto & DeGirolamo, 2012). Studies are needed that combine these factors and examine how the learning condition and different recall tasks influence young and older people's spatial mental representations to better explore the features and flexibility of older adults' cognitive maps, given that switching perspective (i.e., learning from one view and being tested from another) can reveal the goodness of a mental map (e.g., Iglói et al., 2009; Wiener & Mallot, 2003). Exploring the features of older adults' spatial representations using different learning and recall task conditions (from a survey vs. a route perspective) could clarify to what extent their mental representations retain the same perspective or can change it.

Rationale and aim of the study

Given the above premises, the present study aimed to compare the age-related differences in the ability to learn spatial information by reading maps and by navigating in a video (Moffat, 2009; Richardson et al., 1999). Spatial recall was tested with different tasks, one resembling the format of the map reading phase (i.e., a sketch map completion task), the other resembling the format of video learning (i.e., a route repetition task). Since the aim was to compare the same path learned and tested from a survey and a route view, a specific route in the environment was chosen (rather than leaving participants free to explore).

As we were interested in examining how spatial representations change with aging, the effect of age was examined in combination with the different learning conditions and recall tasks. Both young-old (the so-called third age) and old-old (fourth age, Baltes, 1996) groups were considered because these two age groups have shown different rates of decline in spatial learning (i.e., with performance worsening over time) after learning from maps (Meneghetti, Muffato, Suitner, De Beni, & Borella, 2015), and by navigating (Barrash, 1994; Gazova et al., 2013). The effect of age is thus explored in relation to the learning condition in each spatial recall task.

A further, complementary aim of our study was to explore the role of other individual visuo-spatial factors, to shed more light on people's spatial learning performance. These visuo-spatial factors include a set of competences, including cognitive abilities, such as visuo-spatial working memory (VSWM), and also visuo-spatial preferences, strategies and attitudes. VSWM is a basic cognitive mechanism defined as the ability to retain and process visuo-spatial information (Logie, 1995). VSWM is one of the so-called small-scale abilities (typically tested with paper and pencil tasks), and research has shown that they predict performance in large-scale environments too (Hegarty et al., 2006; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006). For instance, VSWM influences route learning (Garden, Cornoldi, & Logie, 2002; Labate, Pazzaglia, & Hegarty, 2014), and learning from maps (e.g., Coluccia, Bosco, & Brandimonte, 2007) in young adults, and there is sound evidence of VSWM having a role in older adults' spatial learning as well (e.g., Borella et al., 2015), despite its age-related decline (Borella, Meneghetti, Ronconi, & De Beni, 2014). Visuo-spatial inclinations are also considered because they have been found related to spatial learning skills. We considered self-reported sense of direction because it is related to efficient spatial performance (in generating spatial descriptions, Hund & Padgitt, 2010; Padgitt & Hund, 2012; and in terms of navigation accuracy, Hegarty et al., 2006). Other self-reported inclinations can be considered (Weisberg, & Newcombe, 2016; Pazzaglia & Meneghetti, 2017), including pleasure in exploring new places or finding new routes in familiar environments (De Beni, Meneghetti, Fiore, Gava, & Borella, 2014). Self-ratings of such abilities (e.g., sense of direction) and attitudes (e.g., pleasure in exploring) are less susceptible to decline over time (Borella et al., 2014), and have also been found positively related to environment knowledge across the life span (Meneghetti, Borella, Pastore, & De Beni 2014). It therefore, seems worth examining whether these individual visuo-spatial characteristics relate to spatial performance at different ages, considering different learning conditions and different spatial recall tasks.

Hypotheses

Concerning the effect of age and learning condition, we expected to find general age-related differences in spatial learning ability, whether spatial information was learned from a map or from a video (situations in which age-related differences had already been reported; Klencklen et al., 2012; Moffat, 2009). For each spatial recall task, there might also be a different influence of the combination of age with learning condition. We specifically explored whether a congruence between the perspective adopted in the learning and recall phases would benefit performance at all ages. It would presumably be cognitively more demanding to switch perspective, so we expected it to be easier for young adults to do so (Shelton & McNamara, 2004; Zhang et al., 2014) than for older adults (Harris et al., 2012). In the light of previous evidence, we might expect strong age-related differences in tasks demanding a different perspective from the one learnt, i.e., a weaker performance in map drawing after learning by navigating, since this involves changing from a route to a survey view (as suggested by Yamamoto & DeGirolamo, 2012; Muffato et al., 2016), and after learning from a map in other types of task (Salthouse & Siedlecki, 2007), such as the route repetition task in our study (which involves changing from a survey to a route view). We also expected to find a decline from young-old to old-old age, based on evidence of differences in studies using map learning at least (see Meneghetti, Muffato, Borella, & De Beni, 2018), and we explore this in relation to the combination of learning conditions and recall modalities.

As for the role of individual visuo-spatial factors, we expected to find that individual abilities and attitudes influenced accuracy in recall tasks (e.g., Meneghetti et al., 2014; Muffato et al., 2017). We assumed that VSWM and self-assessed sense of direction and pleasure in exploring can per se affect spatial recall performance, after accounting for the effect of both age (since these abilities and attitudes influence spatial learning across the life span; e.g., Borella et al., 2014), and learning condition (because they influence learning from both a survey and a route perspective, as seen in young adult studies, e.g., Meneghetti, Pazzaglia, & De Beni, 2011).

Method

Participants

The study involved 127 participants: 46 young adults (aged 25–34; 23 females), 43 young-old adults (aged 65–74; 23

Table 1 Means (*M*) and standard deviations (SD) of the sample's demographics

	Young ($N=46$)		Young-old ($N=43$)		Old-old ($N=38$)	
	M	SD	M	SD	M	SD
Age	27.41	2.67	67.33	2.42	78.34	3.20
Years of formal education	14.28	2.74	11.63	3.24	10.13	2.99
Vocabulary test score	46.96	7.58	45.91	8.48	43.58	11.07

females), and 38 old-old adults (aged 75–84; 21 females). All participants volunteered to take part in the experiment. The older participants were all healthy and living independently. They met our inclusion criterion requiring a score of more than 26 in the MoCA (Montreal Cognitive Assessment, Nasreddine et al., 2005). The following were reasons for exclusion from the study: (1) a history of psychiatric, neurological or other diseases capable of causing cognitive, visual, auditory and/or motor impairments (Crook et al., 1986); (2) familiarity with the environments used in the learning phase (i.e., the Botanical Garden and Europe Park in Padua, Italy), which they had to have never visited.

The young-old and old-old groups were less well educated than the young adults, $F(2, 126)=20.96$, $\eta^2=0.25$, $p<.001$, consistently with socio-demographic differences due to the cohort effect (see ISTAT, 2011). All participants had nonetheless completed their compulsory schooling (8 years in Italy). All groups had a similar performance, $F(2, 126)=1.49$, $p=.23$, in the vocabulary test (Wechsler, 1981), which assesses crystallized abilities. Table 1 shows the participants' characteristics.

The Ethical Committee for Psychological Research at the University of Padova approved the study. 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).

Materials

Session 1: individual visuo-spatial measures

Jigsaw Puzzle Test (JPT, De Beni, Borella, Carretti, Marigo, & Nava, 2008) This VSWM task (adapted from Richardson & Vecchi, 2002) comprises 27 puzzles containing increasing numbers of pieces (from 2 to 10), and representing very familiar objects. The task involves mentally recomposing the picture by indicating how the pieces should be placed in an empty grid, without actually moving the pieces. There are three puzzles for each level of difficulty. To proceed to the next level, participants must solve at least two of the three puzzles on a given level of difficulty. The final score is the sum of the levels of the three most difficult puzzles solved (max. 29).

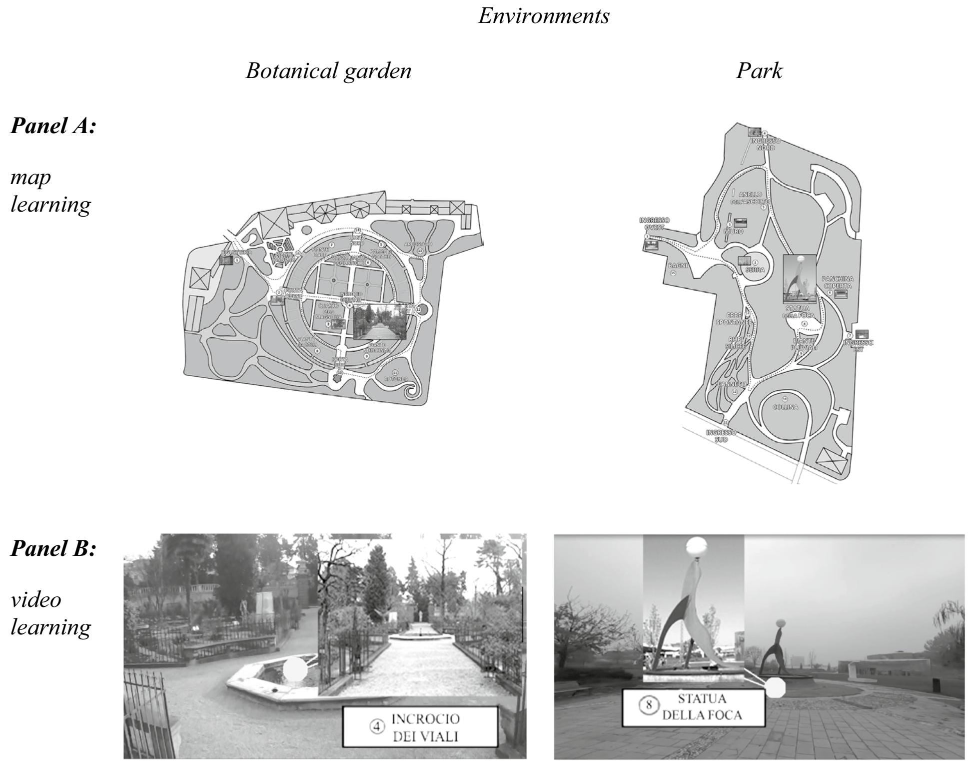
Sense of Direction and Spatial Representation Scale (SDSR, De Beni et al., 2014; adapted from Pazzaglia, Cornoldi, & De Beni, 2000) This task involves judging 13 items, on a Likert scale from 1 (not at all) to 5 (very much), that measure general sense of direction, knowledge and use of cardinal points, and a preference for survey, route or landmark-centered representations (e.g., "Do you think you have a good sense of direction?") (Cronbach's $\alpha=0.78$). The final score is the sum of all the item ratings (as in Borella et al., 2014).

Attitudes towards Orientation Tasks Scale (AtOT, De Beni et al., 2014) This involves judging ten items, on a Likert scale from 1 (not at all) to 6 (very much), that relate to pleasure in exploring places (e.g., "I like to find new ways to reach familiar places"; five items) or no pleasure in exploring places ("When I'm travelling or visiting a new city I like somebody to guide me"; five items). The score is calculated after reversing the scores for the 'no pleasure' items (max. 60), and higher scores indicate greater pleasure in exploring (Cronbach's $\alpha=0.77$) (as in Meneghetti & Muffato, 2017).

Session 2: environment learning and recall measures

Two real environments were identified, i.e., the Botanical Garden and the "Europe" park, both in Padova (Italy). Each environment included a total of 15 landmarks in similar relative positions: 4 were named after the cardinal points (the north, south, east and west gates at the Botanical Garden; and the north, south, east and west entrances to the park); 1 was situated roughly in the middle of the area (the crossroads at the Botanical Garden; and the glasshouse in the park); and 10 were natural and artificial landmarks within the boundaries of the area (the annual plants, the hillside plants, the magnolia, the medicinal plants, the palm, the pond, the rare plants, the roundabout, the shrubbery, and the ticket office at the Botanical Garden; and the toilets, the covered bench, the hill, the "listening point", the rainforest plants, the rushes, the seal statue, the siliceous cliff plants, the wall, and the wild herbs in the park). The map and video learning conditions presented the landmarks in the same sequence, based on a route along a plausibly walkable path—already traced in the real environment—that covered (i.e., passed alongside) all the landmarks identified in the environment. The paths in each environment were of similar length (about 550 m).

Fig. 1 Screenshots of the map (Panel **A**) and video (Panel **B**) used in the learning phase



Note. "Incrocio dei viali" = The crossroads; "Statua della foca" = The seal statue.

The path in the Botanical Garden started from the west and initially headed south, while the path in the Europe park started from the west and initially headed north. A pilot study ($N=40$ participants) showed that performance correlated closely for the two environments in a map drawing task ($r=0.87$, $p<.001$), and a pointing task ($r=0.76$, $p<.001$). Full-screen maps and videos of the environments were shown on a 15″ PC screen for 6 min each (see screenshots of the environments in Fig. 1).

Environment learning *Map*: Maps of the two environments were prepared using an automatic PowerPoint presentation that lasted 360 s (6 min) in all. For the first 105 s, a map was displayed that showed the whole area with a red dotted line marking the route, and the names and sequential numbers of the landmarks were written in their corresponding locations. Then a red arrow appeared and indicated the route's starting point. A window (5.5×3.5 cm) then appeared, showing an image of the first landmark along the route. After 5 s, the image was reduced in size and placed next to the written name of the corresponding landmark, where it remained for another 5 s. All the other landmarks were displayed in the same way, one after the other, for a total of 150 s for all 15 landmarks (10 s per landmark). The map, complete with all the small pictures depicting the landmarks, then remained on the screen for the last 105 s. This modality was chosen to make the presentation of the landmarks more dynamic than in normal map learning (Yamamoto & DeGirolamo, 2012), and to focus participants' attention on the route.

Video: For each environment, a video following the route from a ground-level perspective was recorded (using a GoPro helmet) and projected on screen using as a .mp4 file. The use of a video tour to learn the environment was preferred because it gives a good approximation of real navigation that is useful in the experimental setting (Moffat, 2009; Richardson et al., 1999). Each video lasted 6 min. When a landmark was encountered along the route, an image (5.5×3.5 cm) of it appeared on the screen for 5 s with a written label showing its name and sequential number, and a yellow dot indicated its location.

Recall measures *Sketch map completion task*: This task involves drawing or writing the names of as many of the landmarks as possible, placing them in the right relationship with one another on a sketch map printed on a sheet of A4 paper. The sketch map showed salient details of the layout of the environments, such as their boundaries, and an arrow indicating the starting point. Sketch map completion accuracy was scored using the Gardony Map Drawing Analyzer (GMDA, Gardony, Taylor, & Brunyé, 2016), and the square root of the canonical organization (SQRT-CO) was considered as a global index of accuracy (for details see Gardony et al., 2016; Meneghetti, Muffato, Varotto, & De Beni, 2017). This index is based on a comparison

Table 2 Means (*M*) and standard deviations (SD) of performance in the spatial recall tasks by age group and learning condition

	Young		Young-old		Old-old	
	M	SD	*M*	SD	*M*	SD
Sketch map completion accuracy—after learning from a map (max. 1)	0.76	0.14	0.61	0.18	0.48	0.17
Sketch map completion accuracy—after learning from a video (max. 1)	0.63	0.18	0.50	0.18	0.44	0.18
Route repetition accuracy—after learning from a map (max. 8)	6.48	1.30	4.84	2.19	4.08	2.17
Route repetition accuracy—after learning from a video (max. 8)	6.83	1.30	5.34	2.10	4.05	2.10

between the landmarks' location on the map and their Cartesian coordinates previously calculated on the target layout (scores range from 0 to 1).

Route repetition task: The task involves watching a video of a previously-learned path with landmarks that appear along the way, but their names are not shown, and deciding (at 8 points) which way to proceed along the path (i.e., going straight on, turning left or right) when the video is paused. If the wrong way is chosen, feedback showing the right way is provided and the video continues in the right direction. For scoring purposes, one point was awarded for a correctly taken direction, and the sum of the correct answers was calculated (range 0–8).

Procedure

Participants individually attended two sessions lasting a total of 80 min. At the first session, they completed a socio-demographic questionnaire and the MoCA (only for the older participants), the vocabulary test, the JPT, and the visuo-spatial questionnaires. During the second session, they learned the route through one of the environments from a map or video, then they were administered the sketch map completion and route repetition tasks. They were then asked to learn the route through the other environment, which was presented in the learning format not used before (video or map), and again completed the two spatial recall tasks. The learning condition and recall tasks were presented in a balanced order across participants.[1]

[1] A participant could be assigned to one of the following four combinations: (i) map learning, sketch map task, route repetition task; then video learning, sketch map task, route repetition task; (ii) video learning, sketch map task, route repetition task; then map learning, sketch map task, route repetition task; (iii) map learning, route repetition task, sketch map task; then video learning, route repetition task, sketch map task; or (iv) video learning, route repetition task, sketch map task; then map learning, route repetition task, sketch map task.

Results

The effect of age and learning condition

Descriptive statistics

Table 2 shows the mean scores and standard deviations for sketch map completion (SQRT-CO) and route repetition accuracy by age group and learning condition.

Regression models

To shed more light on the effect of age and learning condition, linear models were run on sketch map completion and route repetition accuracy. The analysis was conducted with the R software.

Regression analyses were run in steps to explore whether or not the variables inserted improved the model. Gender and years of schooling were entered in a baseline model (step 0). In a preliminary phase, balancing order was also inserted in the model at this baseline level, but it was not a predictor of accuracy in the sketch map completion or route repetition tasks, nor did it influence any other effect, so it was not considered in the subsequent analyses. Gender and educational level (years of schooling) were retained in the baseline model, however, to identify the effect of age and learning condition after controlling for these variables, which are known to relate to spatial performance (e.g., see Coluccia & Louse, 2004 for gender; Ardila, 2000 for education). Age group (young vs. young-old vs. old-old), and learning condition (map vs. video) were added in a first step, with "young adults" as the baseline category for group, and "map" for learning condition. Then the group × learning condition interaction was calculated in step 2.

An evidence ratio (ER) based on the Akaike Information Criterion (AIC) was used to analyze any improvement in the model in subsequent steps. This ratio was calculated as $ER = Exp([AIC_{M1} - AIC_{M2}]/2)$ and can be interpreted as how much a model is likely to be better with a given effect than without it (Wagenmakers & Farrell, 2004).

Sketch map completion task In terms of the SQRT-CO for this task (see Table 3), years of schooling had a significant

Table 3 Evidence ratios for each model, with β values, confidence intervals and p values for each predictor of sketch map completion and route repetition accuracy in the regression models

Predictors	SQRT-CO sketch map completion				Route repetition accuracy			
	ER	*β*	CI	*p*	ER	*β*	CI	*p*
Step 0								
Gender		−0.06	−0.17 to 0.05	0.29		−0.16	−0.27 to −0.05	0.006
Years of schooling		0.47	0.36 to 0.58	<0.001		0.41	0.30 to 0.52	<0.001
Step 1	3×10^{10}				5×10^{9}			
Group: young vs. young-old		−0.20	−0.32 to −0.08	0.001		−0.26	−0.38 to −0.13	<0.001
Group: young vs. old-old		−0.34	−0.47 to −0.21	<0.001		−0.42	−0.55 to −0.28	<0.001
Learning condition: map vs. video		−0.23	−0.33 to −0.13	<0.001		0.07	−0.04 to 0.17	0.200
Step 2	1×10^{1}				0.59			
Group (young vs. young-old) × learning condition (map vs. video)		0.05	−0.08 to 0.19	0.37		0.03	−0.16 to 0.21	0.763
Group (young vs. old-old) × learning condition (map vs. video)		0.16	0.02 to 0.29	0.02		−0.06	−0.24 to 0.12	0.506

SQRT-CO square root canonical organization, *ER* evidence ratio based on AIC of the models

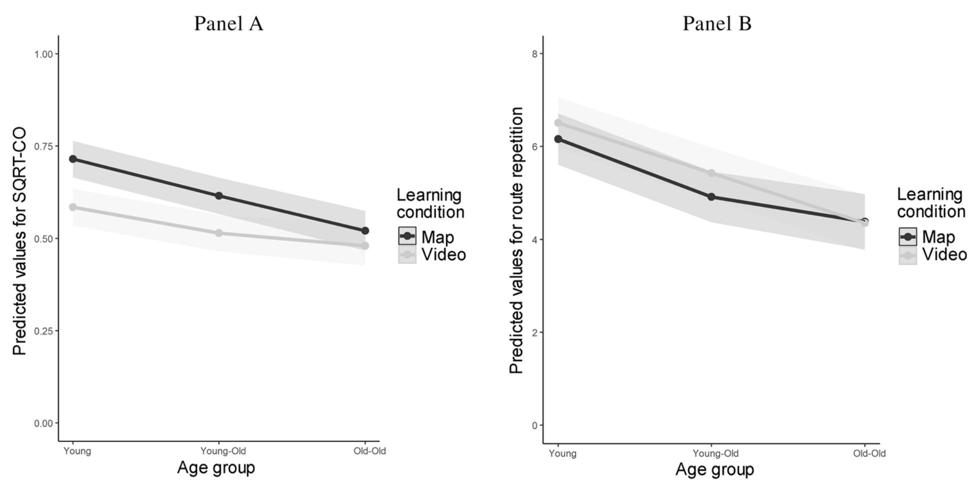


Fig. 2 Learning condition by age group on sketch map completion accuracy (SQRT-CO; Panel **A**) and route repetition accuracy (Panel **B**)

effect at the baseline. In the next step, inserting the group and learning condition contributed to improving the model: the young adults performed significantly better than the young-old or old-old groups; and sketch maps were completed more accurately after learning from a map than from a video. The group × learning condition interaction improved the model too (see ER in Table 3): the young and young-old performed better after learning from a map than from a video, while the old-old's performance remained the same whether they learned from a map or a video (see Fig. 2, panel a).

Route repetition task Years of schooling and gender (with males outperforming females) both had a significant effect at the baseline in this task (see Table 3). Inserting group and learning condition in the next step contributed to improving the model (see ER in Table 4), but the only significant effect was due to the young performing better than the others, while the young-old's and old-old's performance did not differ significantly; and route repetition performance was the same after learning from a map or from a video. The group × learning condition interaction did not improve the model (see Fig. 2, panel B).

The role of visuo-spatial factors

Preliminary analysis

A series of ANOVA were run to confirm a decline in visuo-spatial cognitive abilities, but stable visuo-spatial inclinations with aging (Borella et al., 2014), inputting age group (young vs. young-old vs. old-old) as the dependent variable and each visuo-spatial factor [VSWM (JPT), sense of direction (SDSR), and pleasure in exploring (AtOT)] as

Table 4 Means (*M*) and standard deviations (SD) for scores in the VSWM test and concerning self-assessed spatial inclinations by age group and learning condition

	Young		Young-old		Old-old	
	M	SD	*M*	SD	*M*	SD
VSWM (max. 29)	23.33	4.54	17.63	4.15	12.18	4.26
SDSR (max. 65)	36.46	7.59	37.70	8.60	37.39	8.10
AtOT—pleasure in exploring (max. 60)	32.83	8.55	30.84	10.47	26.26	10.22

VSWM visuo-spatial working memory (Jigsaw Puzzle Test, JPT), *SDSR* Sense of Direction and Spatial Representation Scale, *AtOT* Attitudes to Orientation Tasks

Table 5 Correlations between age, visuo-spatial factors, and recall task performance

	1	2	3	4	5	5	7
1. Age	–						
2. VSWM (JPT)	**−0.71**	–					
3. SDSR	0.08	0.16	–				
4. AtOT—pleasure in exploring	**−0.23**	**0.44**	**0.57**	–			
5. SQRT-CO—after learning from a map	**−0.57**	**0.65**	0.12	**0.36**	–		
6. SQRT-CO—after learning from a video	**−0.41**	**0.39**	**0.25**	**0.36**	**0.57**	–	
7. Route repetition accuracy—after learning from a map	**−0.46**	**0.56**	0.12	**0.40**	**0.47**	**0.44**	–
8. Route repetition accuracy—after learning from a video	**−0.50**	**0.55**	**0.20**	**0.48**	**0.49**	**0.45**	**0.57**

$N = 127$

VSWM visuo-spatial working memory (Jigsaw Puzzle Test, JPT), *SDSR* Sense of Direction and Spatial Representation scale, *AtOT* Attitudes to Orientation Tasks, *SQRT-CO* Square Root Canonical Organization

Significant correlations in bold type: for $|r| \geq 0.18$, $p < .05$; for $|r| \geq 0.23$, $p < .01$, and for $|r| \geq 0.27$, $p < .001$.

independent variables. Post hoc analyses were run using Bonferroni's correction (assuming significance for a difference with $p < .02$). See Table 4 for the descriptive values of the visuo-spatial measures.

As expected, the groups differed significantly in the JPT, $F(2, 124) = 69.31$, $\eta_p^2 = 0.53$, $p < .001$. Post hoc analyses showed that the young adults scored better than either of the other groups ($p_s < .001$), and the young-old outperformed the old-old ($p < .001$). The groups did not differ significantly in their total SDSR scores, $F(2, 124) = 1.77$, $p = .17$. They did differ significantly, however, in terms of their pleasure in exploring, $F(2,124) = 4.87$, $\eta_p^2 = 0.07$, $p = .009$. Post hoc analyses showed that the old-old enjoyed exploring less than the young adults ($p = .008$), while the young-old group did not differ significantly from either the young ($p = 1.00$), or the old-old ($p = .11$).

Pearson's correlations were also run between age, visuo-spatial factors, and spatial recall tasks to seek any relationships between visuo-spatial factors and spatial performance (see Table 5). The scores for VSWM (JPT) and pleasure in exploring (AtOT) correlated significantly with accuracy in both spatial recall tasks (sketch map completion and route repetition). The SDSR score correlated with recall task performance after learning from a video, and it correlated strongly with pleasure in exploring.

Regression models: last step

To further clarify the role of visuo-spatial factors, the JPT, SDSR and AtOT scores were added in a third (last) step to the models described in the previous section. They were input last to see whether they were still able to predict spatial performance over and above the other factors (i.e., gender and educational level in step 0, age group and learning condition in step 1, and their interaction in step 2).

Regarding sketch map completion accuracy, adding this step improved the model ($ER = 1 \times 10^4$, compared to step 2, described above): a better VSWM (std. $\beta = 0.20$, CI 0.05–0.36, $p = .01$) and greater self-reported pleasure in exploring (std. $\beta = 0.15$, CI 0.02–0.28, $p = .03$) coincided with a greater accuracy in completing the sketch map (while there was no effect of sense of direction: std. $\beta = 0.08$, CI −0.05 to 0.20, $p = .22$).

The same applied to route repetition accuracy ($ER = 8 \times 10^8$): a better VSWM (std. $\beta = 0.25$, CI 0.09–0.40, $p = .002$) and greater self-reported pleasure in exploring (std. $\beta = 0.28$, CI 0.14–0.41, $p < .001$) coincided with a better performance in the route repetition task too (and, here again, sense of direction had no effect: std. $\beta = -0.05$, CI −0.17 to 0.08, $p = .47$).

These results demonstrate that accuracy in performing both recall tasks related to VSWM and self-assessed pleasure in exploring.

Discussion and conclusion

The present study aimed to analyze age-related differences in spatial representations in young, young-old and old-old adults when two learning conditions, from maps and from navigation videos (i.e., from a survey and a route perspective, respectively), were used in combination with spatial recall tasks that adopted perspectives similar to, or different from those used in the learning phase, i.e., a sketch map completion task consistent with learning from a map, and a route repetition task consistent with learning from a video. The influence on recall task accuracy of VSWM and self-assessed visuo-spatial inclinations was also explored.

The results are presented and discussed here, based on the effect of learning condition and its interaction with age in spatial task accuracy. It should be noted that the results are reported after accounting for the known effects of educational level and gender on performance (e.g., Ardila, 2000; Lawton, 1994), especially on spatial recall accuracy, whereas preliminary analyses had shown that the balancing order of the learning conditions and recall tasks had no influence.

Concerning the role of the type of learning input vis-à-vis the type of recall task, our results show that, in a sketch map completion task (requiring a survey-focused knowledge), participants generally benefited from having learned from a map (survey view) rather than from a video (route view). These results are consistent with spatial cognition models indicating that learning from a map (survey perspective) generates configurational knowledge (Richardson et al., 1999) that is easier to use in a sketch map completion task than information gleaned from a video (route perspective). Adapting input learned from one perspective (as in a video tour) to produce an output requiring the other perspective (as in the sketch map completion task) is more difficult, and individual differences may influence the ability to switch from egocentric to allocentric knowledge (Iglói et al., 2009; Wiener & Mallot, 2003). In general, the greater difficulty of a task that involves switching from an egocentric (learning by navigating) to an allocentric approach (in the sketch map completion task)—by comparison with a situation in which no change of perspective is needed—seems to corroborate the model according to which egocentric knowledge is gained earlier than allocentric knowledge (Siegel & White, 1975). When spatial information is learned egocentrically and a mental representation is formed, its egocentric features are readily accessible, whereas the allocentric features of the representation are less so, and can only be retrieved at a cost in terms of accuracy.

On the other hand, we found that performance in solving a route repetition task did not depend on whether the route had been learned from a map or from a video. In other words, no such advantage of using the same perspective as in the learning condition emerged for the route repetition task, nor did having to switch perspective in the recall phase prove to be a disadvantage. This result seems to contrast with previous reports of a benefit when route-based knowledge was tested with route-based tasks (Thorndyke, & Hayes-Roth, 1982; Taylor et al., 1999). The discrepancy may relate to the features of the learning conditions and the route repetition task. For instance, our map showed not only the layout of the landmarks in the area (clearly structured with borders) but also the route to travel from one to the next. This well-marked route (in both learning conditions) may have provided enough information to enable participants to manage the route repetition task equally well, regardless of whether they had learned from a map or a video. Our route repetition task also involved deciding which way to go (turning left, turning right, or going straight on), unlike route recall tasks used in other studies which involved estimating distances along a route (as in Thorndyke, & Hayes-Roth, 1982), or describing paths (as in Taylor et al., 1999), finding a beneficial effect of learning from a route perspective. Given these differences, the results obtained with our route repetition task may not be fully comparable with findings emerging when other route tasks were administered.

Taken together, our results regarding the effects of learning condition give us a first demonstration that the way in which people learn environmental information needs to be considered together with the nature of the recall task they are administered. In particular, a task demanding recall from a survey perspective (like our sketch map completion task) is easier if the information required is learned from the same survey perspective, and more difficult if it is learned from a route perspective (as in our video). When the task involves repeating a route (based in points where respondents choose which way to go), learning from a video or from a map makes no difference to performance.

These results can be better contextualized by analyzing the role of learning condition and age together. Our results show that performance in the sketch map completion task and route repetition task deteriorated with age, and this is in line with previous studies showing an age-related decline in performance in spatial recall tasks (Klencklen et al., 2012; Moffat, 2009). When the interaction between age and learning condition was considered, however, we found a different effect of age and learning condition on the different types of task.

In completing the sketch map, young adults benefited from having learned from a map rather than from a video. Although their performance was weaker, this was also true of the young-old, i.e., young-old adults can still perform better if they learn from a map before completing a sketch map task. The old-old's map completion performance was no longer influenced by the learning condition, however. These findings are consistent with the report from Yamamoto and DeGirolamo (2012) that older adults' performance in a sketch map task was impaired by comparison with that of young adults if they had learned from exploratory navigation (from a first-person point of view) but not if they had learned from a map. Given that allocentric abilities seem more age-sensitive across the life span than egocentric abilities (Ruggiero, D'Errico, & Iachini, 2016), presenting input from a survey perspective and then testing its recall with a task presented from the same perspective could help to prevent any age-related decline in performance, in young-old adults, at least, as previously suggested (Yamamoto & DeGirolamo, 2012; Meneghetti, Borella, Grasso, & De Beni, 2012). The present study provides further evidence of this benefit (of learning from a map rather than from a video before completing a sketch map task) applying only to the young-old, not to old-old adults. This may be attributable to a gradual cognitive decline from the third to the fourth age (Gazova et al., 2013; Ruggiero et al., 2016), with the latter revealing impairments similar to those seen in pathological aging (e.g., Morganti, Stefanini, & Riva, 2013). This issue needs to be further analyzed in future studies.

Concerning route repetition accuracy, the interaction between age and learning condition was not significant, meaning that none of the age groups benefited more than the others from a congruent learning condition (i.e., learning from a video rather than from a map) when it came to performing the route repetition task. As mentioned earlier, solving the route repetition task involved deciding which way to go at certain points along a route, and the information needed to do so could be learned equally well from our maps and our videos at any age. Our results concerning the age-related impairment in route repetition performance are in line with previous findings, however, and highlight a gradual decline in the ability to repeat a previously learnt route (e.g., Muffato et al., 2016) and to obtain information from a map in old age (Wilkniss et al., 1997), especially for people over seventy (Barrash, 1994), as in our old-old group.

Taken together, these results support the notion that learning from a map or a from a video (navigating) may differently affect how young and older adults manage spatial information, as elicited by different types of recall task. This would extend to older age groups the partially independent model of spatial learning emerging from studies on young adults (Zhang et al., 2014): learning from different perspectives may prompt mental representations with different features (as in our case, when learning from a map made it easier to complete the sketch map), but this is not always the case (learning from a map or from a video had no influence on our participants' route repetition performance). This is also consistent with neurobiological studies on aging, which have demonstrated an activation of partially different networks, i.e., the posteromedial and mediotemporal cerebral areas (relying primarily on the hippocampus) for allocentric knowledge, and the posterior parietal/frontal areas for egocentric knowledge (relying primarily on the caudate nucleus) (Colombo et al., 2017; Galati, Pelle, Berthoz, & Committeri, 2010; Harris et al., 2012), both in the learning phase and in the retrieval of spatial information (Boccia et al., 2016). Degeneration in the hippocampus and its connections (such as a reduced hippocampal connectivity to prefrontal areas) may explain spatial impairments in older people, especially when switching perspective, in both healthy aging (Grady, McIntosh, & Craik, 2003) and mild cognitive impairment, or Alzheimer's disease (Serino, Cipresso, Morganti, & Riva, 2014). Future studies on older adults will need to better explore this switching ability, however.

Finally, it is worth underscoring how VSWM and self-assessed spatial inclinations contribute to spatial mental representations, after accounting for the role of age and learning condition. Our results confirmed the well-established notion that VSWM declines with age (Borella et al., 2014; Techentin, Voyer, & Voyer, 2014), while self-assessed visuo-spatial inclinations remain stable over the adult life span (Borella et al., 2014). Our findings newly indicate the simultaneous role of visuo-spatial cognitive abilities and self-reported inclinations as predictors of spatial performance. In both a sketch map completion task and a route repetition task, after controlling for age and learning condition, a better VSWM predicted a better performance. For the former task, there was already evidence of VSWM affecting performance after learning from a map, in both young (Coluccia et al., 2007) and older adults (Borella et al., 2015; Muffato et al., 2017), and our results confirmed that this applies over and above the influence of learning condition and age. For the latter task, previous studies had produced less consistent results, some finding VSWM unrelated to navigation performance in aging (Taillade, N'Kaoua, & Sauzéon, 2016), while others found the opposite (Mitolo et al., 2015). Our results seem to suggest a role for VSWM when spatial information is learned by navigating too, confirming findings regarding environmental learning from a life span perspective (e.g., Meneghetti et al., 2014).

VSWM is not the only factor to consider, however. As some studies have shown, other abilities and self-reported inclinations support environment learning in older adults (Meneghetti et al., 2014; Borella et al., 2014). In particular, our results point to an emerging role for pleasure in exploring (which is correlated with sense of direction) in influencing spatial performance. The propensity to find pleasure in exploring is a personal attitude that seems to remain fairly stable over the years (De Beni et al., 2014); in fact, we only found scores dropping in the old-old. This self-perception is related to a functional spatial profile (De Beni et al., 2014), it correlates positively with self-reported scores for sense of direction, and it can help an individual learn spatial information efficiently. Although these findings show that it is important to consider people's spatial abilities (such as VSWM) jointly with their beliefs concerning their spatial expertise (e.g., Wen, Ishikawa, & Sato, 2013) as predictors of their spatial performance, further studies should better address the contribution of individual visuo-spatial factors, such as personal attitudes to exploring and spatial learning abilities (testing different learning conditions and recall tasks), especially in old age.

To sum up, the novelty of the present study lies in that it goes beyond the well-investigated comparison between the influence of a survey vs. a route perspective (map vs. navigation) in the learning condition per se, combining them with different types of recall task (in terms of the perspective adopted: a survey perspective in a sketch map completion task vs. a route perspective in a route repetition task) at different ages. This is particularly important in assessing the effects of aging on people's spatial representation abilities when the perspective used in the learning phase is combined with recall requests that adopt the same or different perspectives. In fact, the present study highlights the effects of age when combined with spatial information learnt from a survey or route perspective. Despite a decline with aging, young-old (but not old-old) adults' performance still benefited when they completed a sketch map task after learning from a map rather than from a video. The learning condition had no influence on the route repetition task, however, in which a general age-related decline was apparent. After controlling for age and learning condition, spatial recall performance was further influenced by individual visuo-spatial factors, in terms of both visuo-spatial abilities (VSWM) and attitude (pleasure in exploring).

These results offer new insight in the aging domain, shedding more light on the strengths and weaknesses of older people's spatial learning. Some limitations of this study need to be mentioned, however, along with some still open issues to address. First of all, one limitation derives from the nature of our materials, as mentioned earlier, and particularly from the characteristics of the route repetition task based on identifying which way to go in a video (which can be considered a multiple-choice task as participants had to decide between going straight on, turning left or turning right). Other route finding tasks involve actively reproducing a path (e.g., the route execution task, Kirasic, 2000). The characteristics of our route repetition task may have generated less variation in participants' task performance. On the other hand, our sketch map completion task involved actively recalling landmarks and locating them in a layout, and therefore, demanded a more in-depth management of the spatial information learned. This difference in the demands of the two tasks used in our study may explain the lack of interaction with learning condition in the case of the route repetition task. The advantage (or disadvantage) of having learnt a route by navigating it when performing a route-focused recall task consequently warrants further investigation. Navigation is a complex practice that can involve not only passive experience (as in our study, learning from a video and solving our route repetition task), but also active engagement, as in the case of participants freely exploring an environment, whether in the learning and/or testing phase. So, future studies need to explore more thoroughly whether our results are attributable to an age-related decline in route learning skills per se, or depend on the features of the learning input and/or recall tasks. Another open issue concerns the influence of individual factors. We found participants' educational level relevant when assessing their performance in both the sketch map completion and the route repetition tasks, and gender influenced performance in the route repetition task. In the present study, spatial performance was analyzed after accounting for the role of education and gender at the baseline (as our aim was to investigate the effects of age and learning condition). It will be interesting to investigate their contributions, however (as seen for education in Ardila, 2000; and for gender in Lawton, 1994). The role of education seems especially interesting, given its importance for the cognitive reserve (e.g., Stern, 2009), and this could be investigated by considering different groups of older adults with more and fewer years of schooling, for instance (e.g., Van Hooren et al., 2006).

It is also worth examining the influence of different spatial information inputs in combination. It is common in real life to use such combinations, such as navigating to a place while consulting a map on the way, and combining the two perspectives can generate an effective mental map for accessing both egocentric and allocentric information (Sjolinder, Hook, Nilsson, & Andersson, 2005; Wilkniss et al., 1997). Future research should, therefore, look into the transfer of knowledge gained by reading a map or navigating in an environment, and by combining the two (getting participants to move around in an environment after looking at a map, for instance), assessing recall using different modalities. This type of study on older people should also be considered for possible applications in the early detection of cognitive impairments, as some of the first symptoms of Alzheimer's disease, for instance, relate to the spatial domain (Serino, Morganti, Di Stefano, & Riva, 2015).

To conclude, the present study sheds light on the characteristics of people's spatial mental representations. External factors, such as learning condition and type of recall task, and internal factors like age and visuo-spatial abilities and attitudes, influence the features of our mental representations.

Acknowledgements The authors would like to thank Giovanni Leone for helping with video recording, and Annarita Lepre and Martina Nicolis for helping with data collection.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to disclose.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

Ardila, A. (2000). Age-related cognitive decline during normal aging: The complex effect of education. *Archives of Clinical Neuropsychology, 15*, 495–513. https://doi.org/10.1016/S0887-6177(99)00040-2.

Baltes, M. (1996). The psychology of the oldest-old: The fourth age. *Current Opinion in Psychiatry, 11*, 411–415.

Barrash, J. (1994). Age-related decline in route learning ability. *Developmental Neuropsychology, 10*, 189–201. https://doi.org/10.1080/87565649409540578.

Blades, M. (1990). The reliability of data collected from sketch maps. *Journal of Environmental Psychology, 10*, 327–339. https://doi.org/10.1016/S0272-4944(05)80032-5.

Boccia, M., Guariglia, C., Sabatini, U., & Nemmi, F. (2016). Navigating toward a novel environment from a route or survey perspective: Neural correlates and context-dependent connectivity. *Brain Structure and Function, 221*, 2005–2021. https://doi.org/10.1007/s00429-015-1021-z.

Borella, E., Meneghetti, C., Muffato, V., & De Beni, R. (2015). Map learning and the alignment effect in young and older adults: How do they gain from having a map available while performing pointing tasks? *Psychological Research Psychologische Forschung, 79*, 104–119. https://doi.org/10.1007/s00426-014-0543-y.

Borella, E., Meneghetti, C., Ronconi, L., & De Beni, R. (2014). Spatial abilities across the adult life span. *Developmental Psychology, 50*, 384–392. https://doi.org/10.1037/a0033818.

Colombo, D., Serino, S., Tuena, C., Pedroli, E., Dakanalis, A., Cipresso, P., & Riva, G. (2017). Egocentric and allocentric spatial reference frames in aging: A systematic review. *Neuroscience and Biobehavioral Reviews, 80*, 605–621. https://doi.org/10.1016/j.neubiorev.2017.07.012.

Coluccia, E., Bosco, A., & Brandimonte, M. A. (2007). The role of visuo-spatial working memory in map learning: New findings from a map drawing paradigm. *Psychological Research Psychologische Forschung, 71*, 359–372. https://doi.org/10.1007/s00426-006-0090-2.

Coluccia, E., & Louse, G. (2004). Gender differences in spatial orientation: A review. *Journal of Environmental Psychology, 24*, 329–340. https://doi.org/10.1016/j.jenvp.2004.08.006.

Crook, T., Bartus, R. T., Ferris, S. H., Whitehouse, P., Cohen, G. D., & Gershon, S. (1986). Age-associated memory impairment: Proposed diagnostic criteria and measures of clinical change—report of a National Institute of Mental Health work group. *Developmental Neuropsychology, 2*, 261–276. https://doi.org/10.1080/87565648609540348.

Cushman, L. A., Stein, K., & Duffy, C. J. (2008). Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. *Neurology, 71*, 888–895. https://doi.org/10.1212/01.wnl.0000326262.67613.fe.

De Beni, R., Borella, E., Carretti, B., Marigo, C., & Nava, L. A. (2008). *Portfolio per la valutazione del benessere e delle abilità cognitive nell'età adulta e avanzata [The assessment of well-being and cognitive abilities in adulthood and aging]*. Firenze: Giunti OS.

De Beni, R., Meneghetti, C., Fiore, F., Gava, L., & Borella, E. (2014). *Batteria Visuo-spaziale. Strumenti per la valutazione delle abilità visuo-spaziali nell'arco di vita adulta [Visuo-spatial battery: Instrument for assessing visuo-spatial abilities across adult life span]*. Firenze: Hogrefe.

Devlin, A. L., & Wilson, P. H. (2010). Adult age differences in the ability to mentally transform object and body stimuli. *Aging, Neuropsychology, and Cognition, 17*, 709–729. https://doi.org/10.1080/13825585.2010.510554.

Galati, G., Pelle, G., Berthoz, A., & Committeri, G. (2010). Multiple reference frames used by the human brain for spatial perception and memory. *Experimental Brain Research, 206*, 109–120. https://doi.org/10.1007/s00221-010-2168-8.

Garden, S., Cornoldi, C., & Logie, R. H. (2002). Visuo-spatial working memory in navigation. *Applied Cognitive Psychology, 16*, 35–50. https://doi.org/10.1002/acp.746.

Gardony, A. L., Taylor, H. A., & Brunyé, T. T. (2016). Gardony Map Drawing Analyzer: Software for quantitative analysis of sketch maps. *Behavior Research Methods, 48*, 151–177. https://doi.org/10.3758/s13428-014-0556-x.

Gazova, I., Laczó, J., Rubinova, E., Mokrisova, I., Hyncicova, E., Andel, R., & Hort, J. (2013). Spatial navigation in young versus older adults. *Frontiers in Aging Neuroscience*. https://doi.org/10.3389/fnagi.2013.00094.

Grady, C. L., McIntosh, A. R., & Craik, F. I. M. (2003). Age-related differences in the functional connectivity of the hippocampus during memory encoding. *Hippocampus, 13*, 572–586. https://doi.org/10.1002/hipo.10114.

Harris, M. A., Wiener, J. M., & Wolbers, T. (2012). Aging specifically impairs switching to an allocentric navigational strategy. *Frontiers in Aging Neuroscience*. https://doi.org/10.3389/fnagi.2012.00029.

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude test performance and spatial layout learning. *Intelligence, 34*, 151–176. https://doi.org/10.1016/j.intell.2005.09.005.

Hund, A. M., & Padgitt, A. J. (2010). Direction giving and following in the service of wayfinding in a complex indoor environment. *Journal of Environmental Psychology, 30*, 553–564. https://doi.org/10.1016/j.jenvp.2010.01.002.

Iglói, K., Zaoui, M., Berthoz, A., & Rondi-Reig, L. (2009). Sequential egocentric strategy is acquired as early as allocentric strategy: Parallel acquisition of these two navigation strategies. *Hippocampus, 19*, 1199–1211. https://doi.org/10.1002/hipo.20595.

ISTAT. (2011). Annuario statistico italiano 2011 (Italian Statistics Yearbook 2011). Rome: ISTAT.

Jansen, P., Schmelter, A., & Heil, M. (2010). Spatial knowledge acquisition in younger and elderly adults. *Experimental Psychology, 57*, 54–60. https://doi.org/10.1027/1618-3169/a000007.

Kirasic, K. C. (2000). Age differences in adults' spatial abilities, learning environmental layout, and wayfinding behavior. *Spatial Cognition and Computation, 2*, 117–134. https://doi.org/10.1023/a:1011445624332.

Klencklen, G., Després, O., & Dufour, A. (2012). What do we know about aging and spatial cognition? Reviews and perspectives.

Ageing Research Reviews, 11, 123–135. https://doi.org/10.1016/j.arr.2011.10.001.
Kozhevnikov, M., Motes, M. A., Rasch, B., & Blajenkova, O. (2006). Perspective-taking vs. mental rotation transformations and how they predict spatial navigation performance. *Applied Cognitive Psychology, 20*, 397–417. https://doi.org/10.1002/acp.1192.
Labate, E., Pazzaglia, F., & Hegarty, M. (2014). What working memory subcomponents are needed in the acquisition of survey knowledge? Evidence from direction estimation and shortcut tasks. *Journal of Environmental Psychology, 37*, 73–79. https://doi.org/10.1016/j.jenvp.2013.11.007.
Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles, 30*, 765–779. https://doi.org/10.1007/BF01544230.
Lee, P. U., & Tversky, B. (2001). Costs of switching perspectives in route and survey descriptions. In *Proceedings of the Annual Meeting of the Cognitive Science Society*. Retrieved from https://escholarship.org/uc/item/4cz5n7j3
Lithfous, S., Dufour, A., & Després, O. (2013). Spatial navigation in normal aging and the prodromal stage of Alzheimer's disease: Insights from imaging and behavioral studies. *Ageing Research Reviews, 12*, 201–213. https://doi.org/10.1016/j.arr.2012.04.007.
Logie, R. H. (1995). *Visuo-spatial Working Memory*. Hove: L. Erlbaum Associates.
Mellet, E., Laou, L., Petit, L., Zago, L., Mazoyer, B., & Tzourio-Mazoyer, N. (2010). Impact of virtual reality on the neural representation of an environment. *Human Brain Mapping, 31*, 1065–1075. https://doi.org/10.1002/hbm.20917.
Meneghetti, C., Borella, E., Carbone, E., Martinelli, M., & De Beni, R. (2016). Environment learning using descriptions or navigation: The involvement of working memory in young and older adults. *British Journal of Psychology, 107*, 259–280. https://doi.org/10.1111/bjop.12145.
Meneghetti, C., Borella, E., Grasso, I., & De Beni, R. (2012). Learning a route using a map and/or description in young and older adults. *Journal of Cognitive Psychology, 24*, 165–178. https://doi.org/10.1080/20445911.2011.603694.
Meneghetti, C., Borella, E., Gyselinck, V., & De Beni, R. (2012). Age differences in environment route learning: The role of input and recall-test modalities in young and older adults. *Learning and Individual Differences, 22*, 884–890. https://doi.org/10.1016/j.lindif.2012.04.006.
Meneghetti, C., Borella, E., Pastore, M., & De Beni, R. (2014). The role of spatial abilities and self-assessments in cardinal point orientation across the lifespan. *Learning and Individual Differences, 35*, 113–121. https://doi.org/10.1016/j.lindif.2014.07.006.
Meneghetti, C., & Muffato, V. (2017). When environmental information is conveyed using descriptions: The role of perspectives and strategies. In *International conference on spatial information theory* (pp. 235–244). Springer, International Publishing.
Meneghetti, C., Muffato, V., Borella, E., & De Beni, R. (2018). Map learning in normal aging: The role of individual visuo-spatial abilities and implications. *Current Alzheimer Research, 15*, 205–218. https://doi.org/10.2174/1567205014666171030113515.
Meneghetti, C., Muffato, V., Suitner, C., De Beni, R., & Borella, E. (2015). Map learning in young and older adults: The influence of perceived stereotype threat. *Learning and Individual Differences, 42*, 77–82. https://doi.org/10.1016/j.lindif.2015.08.015.
Meneghetti, C., Muffato, V., Varotto, D., & De Beni, R. (2017). How directions of route descriptions influence orientation specificity: The contribution of spatial abilities. *Psychological Research Psychologische Forschung, 81*, 445–461. https://doi.org/10.1007/s00426-016-0754-5.
Meneghetti, C., Pazzaglia, F., & De Beni, R. (2011). Spatial mental representations derived from survey and route descriptions: When individuals prefer an extrinsic frame of reference. *Learning and Individual Differences, 21*, 150–157. https://doi.org/10.1016/j.lindif.2010.12.003.
Mitolo, M., Gardini, S., Caffarra, P., Ronconi, L., Venneri, A., & Pazzaglia, F. (2015). Relationship between spatial ability, visuospatial working memory and self-assessed spatial orientation ability: A study in older adults. *Cognitive Processing, 16*, 165–176. https://doi.org/10.1007/s10339-015-0647-3.
Moffat, S. D. (2009). Aging and spatial navigation: What do we know and where do we go? *Neuropsychology Review, 19*, 478–489. https://doi.org/10.1007/s11065-009-9120-3.
Morganti, F., Stefanini, S., & Riva, G. (2013). From allo- to egocentric spatial ability in early Alzheimer's disease: a study with virtual reality spatial tasks. *Cognitive Neuroscience, 4*, 171–180. https://doi.org/10.1080/17588928.2013.854762.
Muffato, V., Meneghetti, C., & De Beni, R. (2016). Not all is lost in older adults' route learning: The role of visuo-spatial abilities and type of task. *Journal of Environmental Psychology, 47*, 230–241. https://doi.org/10.1016/j.jenvp.2016.07.003.
Muffato, V., Meneghetti, C., Di Ruocco, V., & De Beni, R. (2017). When young and older adults learn a map: The influence of individual visuo-spatial factors. *Learning and Individual Differences, 53*, 114–121. https://doi.org/10.1016/j.lindif.2016.12.002.
Nadel, L. (2013). Cognitive maps. In D. E. Waller & L. E. Nadel (Eds.), *Handbook of spatial cognition* (pp. 115–171). Worcester: American Psychological Association. https://doi.org/10.1037/13936-009.
Nasreddine, Z. S., Phillips, N. A., Bèdirian, V., Charbonneau, S., Whitehead, V., Collin, I., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*, 695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.x.
Padgitt, A. J., & Hund, A. M. (2012). How good are these directions? Determining direction quality and wayfinding efficiency. *Journal of Environmental Psychology, 32*, 164–172. https://doi.org/10.1016/j.jenvp.2012.01.007.
Pazzaglia, F., Cornoldi, C., & De Beni, R. (2000). Differenze individuali nella rappresentazione dello spazio e nell'abilità di orientamento: Presentazione di un questionario autovalutativo. *Giornale Italiano Di Psicologia, 27*, 627–650.
Pazzaglia, F., & Meneghetti, C. (2017). Acquiring spatial knowledge from different sources and perspectives: Abilities, strategies and representations. In J. M. Zacks & H. A. Taylor (Eds.), *Representations in mind and world. Essays inspired by Barbara Tversky* (pp. 120–134). New York: Routledge.
Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory and Cognition, 27*, 741–750. https://doi.org/10.3758/BF03211566.
Richardson, J. T. E., & Vecchi, T. (2002). A jigsaw-puzzle imagery task for assessing active visuospatial processes in old and young people. *Behavior Research Methods, Instruments, and Computers: A Journal of the Psychonomic Society, Inc, 34*, 69–82. https://doi.org/10.3758/BF03195425.
Rovine, M. J., & Weisman, G. D. (1989). Sketch-map variables as predictors of way-finding performance. *Journal of Environmental Psychology, 9*, 217–232. https://doi.org/10.1016/S0272-4944(89)80036-2.
Ruggiero, G., D'Errico, O., & Iachini, T. (2016). Development of egocentric and allocentric spatial representations from childhood to elderly age. *Psychological Research Psychologische Forschung, 80*, 259–272. https://doi.org/10.1007/s00426-015-0658-9.
Salthouse, T. A., & Siedlecki, K. L. (2007). Efficiency of route selection as a function of adult age. *Brain and Cognition, 63*, 279–286. https://doi.org/10.1016/j.bandc.2006.09.006.
Serino, S., Cipresso, P., Morganti, F., & Riva, G. (2014). The role of egocentric and allocentric abilities in Alzheimer's disease: A

systematic review. *Ageing Research Reviews, 16*, 32–44. https://doi.org/10.1016/j.arr.2014.04.004.

Serino, S., Morganti, F., Di Stefano, F., & Riva, G. (2015). Detecting early egocentric and allocentric impairments deficits in Alzheimer's disease: An experimental study with virtual reality. *Frontiers in Aging Neuroscience*. https://doi.org/10.3389/fnagi.2015.00088.

Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(1), 158–170. https://doi.org/10.1037/0278-7393.30.1.158.

Siegel, A. W., & White, S. H. (1975). The development of spatial representations of large-scale environments. *Advances in Child Development and Behavior, 10*, 9–55. https://doi.org/10.1016/S0065-2407(08)60007-5.

Sjolinder, M., Hook, K., Nilsson, L. G., & Andersson, G. (2005). Age differences and the acquisition of spatial knowledge in a three-dimensional environment: Evaluating the use of an overview map as a navigation aid. *International Journal of Human–Computer Studies, 63*, 537–564. https://doi.org/10.1016/j.ijhcs.2005.04.024.

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia, 47*, 2015–2028. https://doi.org/10.1016/j.neuropsychologia.2009.03.004.

Taillade, M., N'Kaoua, B., & Sauzéon, H. (2016). Age-related differences and cognitive correlates of self-reported and direct navigation performance: The effect of real and virtual test conditions manipulation. *Frontiers in Psychology, 6*, 1–12. https://doi.org/10.3389/fpsyg.2015.02034.

Taylor, H. A., Naylor, S. J., & Chechile, N. A. (1999). Goal-specific influences on the representation of spatial perspective. *Memory and Cognition, 27*, 309–319. https://doi.org/10.3758/BF03211414.

Taylor, H. A., & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory and Language, 31*, 261–292. https://doi.org/10.1016/0749-596X(92)90014-O.

Techentin, C., Voyer, D., & Voyer, S. D. (2014). Spatial abilities and aging: A meta-analysis. *Experimental Aging Research, 40*, 395–425. https://doi.org/10.1080/0361073X.2014.926773.

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14*, 560–589. https://doi.org/10.1016/0010-0285(82)90019-6.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55*, 189–208. https://doi.org/10.1037/h0061626.

Van Hooren, S. A. H., Valentijn, A. M., Bosma, H., Ponds, R. W. H. M., Van Boxtel, M. P. J., & Jolles, J. (2007). Cognitive functioning in healthy older adults aged 64–81: A cohort study into the effects of age, sex, and education. *Aging, Neuropsychology, and Cognition, 14*, 40–54. https://doi.org/10.1080/138255890969483.

Wagenmakers, E.-J., & Farrell, S. (2004). AIC model selection using Akaike weights. *Psychonomic Bulletin and Review, 11*, 192–196. https://doi.org/10.3758/BF03206482.

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale—revised*. San Antonio: Psychological Corporation.

Weisberg, S. M., & Newcombe, N. S. (2016). How do (some) people make a cognitive map? Routes, places, and working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 42*, 768–785. https://doi.org/10.1037/xlm0000200.

Wen, W., Ishikawa, T., & Sato, T. (2013). Individual differences in the encoding processes of egocentric and allocentric survey knowledge. *Cognitive Science, 37*, 176–192. https://doi.org/10.1111/cogs.12005.

Wiener, J. M., & Mallot, H. A. (2003). "Fine-to-coarse" route planning and navigation in regionalized environments. *Spatial Cognition and Computation, 3*, 331–358. https://doi.org/10.1207/s15427633scc0304_5.

Wilkniss, S. M., Jones, M. G., Korol, D. L., Gold, P. E., & Manning, C. a. (1997). Age-related differences in an ecologically based study of route learning. *Psychology and Aging, 12*, 372–375. https://doi.org/10.1037/0882-7974.12.2.372.

Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities? *Trends in Cognitive Sciences, 14*, 138–146. https://doi.org/10.1016/j.tics.2010.01.001.

World Medical Association. (2013). World Medical Association Declaration of Helsinki. JAMA, 310, 2191. https://doi.org/10.1001/jama.2013.281053.

Yamamoto, N., & DeGirolamo, G. J. (2012). Differential effects of aging on spatial learning through exploratory navigation and map reading. *Frontiers in Aging Neuroscience, 4*, 1–7. https://doi.org/10.3389/fnagi.2012.00014.

Zhang, H., Zherdeva, K., & Ekstrom, A. D. (2014). Different "routes" to a cognitive map: Dissociable forms of spatial knowledge derived from route and cartographic map learning. *Memory and Cognition, 42*, 1106–1117. https://doi.org/10.3758/s13421-014-0418-x.