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SPATIAL LEARNING FROM MAPS AND NAVIGATION: THE ROLE OF AGE AND VISUO-SPATIAL FACTORS

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Please see the section "5. General conclusion" for a summary of the present dissertation

Introduction

Learning spatial information is an activity typical of everyday life. Take the case of tourists walking along a path in a new city or reading a map of an unfamiliar park. By experiencing an environment, they acquire spatial information and form an internal representation, or cognitive map (the term introduced by Tolman, 1948). Spatial representations are therefore mental representations of the layout of an environment that enable a flexible management of spatial information, such as the positions of objects or salient landmarks, and how they relate to one another and to other features of the environment (Wolbers & Hegarty, 2010). The flexibility of mental spatial representations suggests that they are not necessarily associated with a particular orientation (derived from the source of learning used, for instance). Spatial information can be learned from different inputs, by direct or virtual navigation, for example, or from symbolic support such as maps and verbal descriptions (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). The type of input is an external factor capable of modulating the formation of a mental spatial representation. Along with such external factors intervening in the process, there are also internal factors, such as differences in age, and in individual visuo-spatial factors, which include visuo-spatial abilities and self-assessed spatial preferences, for instance. It is important to consider the influence of these factors, alone and in combination, when analyzing spatial knowledge acquisition (Shelton, Marchette, & Furman, 2013). Taking age, for example, we know that spatial learning is an experience typical of every stage of life, from childhood to old age. We also know that aging coincides with a decline in spatial learning (Klencklen, Després, & Dufour, 2012), when route learning and map reading skills are liable to change (e.g., Wiener, de Condappa, Harris, & Wolbers, 2013), so it is important to study older adults' mental spatial representations. Another factor to consider is an individual's visuo-spatial abilities. Research has demonstrated that these abilities are used for spatial learning by young (e.g., Hegarty et al., 2006) and older adults alike (Meneghetti, Borella, Muffato, Pazzaglia, & De Beni, 2014), and they may be another key to understanding variability in spatial learning performance.

In short, the way in which people acquire spatial information, represent it mentally, and then use their mental representations is fundamentally important in their everyday life, and influenced by both external factors (e.g., type of input) and personal factors (e.g., age and visuo-spatial abilities) that may contribute to better explaining how spatial learning accuracy can vary considerably from one individual to another.

In particular, this dissertation project examined the features of mental spatial representations, analyzing the role of age and visuo-spatial factors. Chapter 1 presents the theoretical frameworks used to describe mental spatial representations, focusing on the role of age and visuo-spatial abilities in spatial learning. Chapter 2 describes the first study conducted as part of a project that aimed to analyze the combined role of age and visuo-spatial factors after young, young-old and old-old adults learned a map of an environment. Chapter 3 illustrates the second study, which focused on route learning from direct navigation in young and older adults, also investigating the role of visuo-spatial factors. Chapter 4 concerns the third and last study involved in the project, which focused on comparing how individuals learned a route from a map and from a video, considering the role of visuo-spatial factors and of age from a lifespan perspective. Table 1 briefly summarizes the content of the three studies. The same general procedure was adopted in all three studies. Participants attended two sessions: in the first, they completed tasks designed to testing their visuo-spatial working memory (VSWM) and visuo-spatial abilities; in the second, after learning spatial information (from a map and/or by navigation), they performed several spatial recall tasks designed to test their mental spatial representations. The project was approved by the Ethical Committee for Psychological Research at the University of Padova. Finally, Chapter 5 contains a general discussion of the relevant results and conclusions drawn on the findings of the project.

Table 1. *Overview of the content of the three studies.*

	Participant age groups	Type of input	Spatial recall tasks	Individual visuo-spatial factors	Chapter
Study 1	40 young vs. 40 young-old vs. 40 old-old adults	Map learning	Map drawing task Sketch map task Pointing task	VSWM Visuo-spatial abilities	2
Study 2	38 young vs. 37 young-old adults	Route learning from direct navigation	Route repetition Map drawing task Pointing task	VSWM Visuo-spatial abilities	3
Study 3	431 adults from 25 to 84 years old (in six age groups)	Map vs. video learning	Route repetition Sketch map drawing task Pointing task	VSWM Visuo-spatial abilities	4

1. Mental spatial representations: theoretical framework

1.1. Theoretical models on spatial cognition

Mental spatial representations have been amply studied ever since Tolman introduced the concept of "cognitive maps" in 1948. In his classic paper *Cognitive maps in rats and men*, Tolman postulated the mental construction of a field map of the environment (Tolman, 1948) having noted that rats placed in a maze were able to find novel routes to reach food by constructing an internal map of the environment. This concept was further developed over the years, up until the recent redefinition of a cognitive map as a flexible internal representation (Wolbers & Hegarty, 2010). Spatial information such as landmarks and their relationships (distances and directions) are managed in a mental representation that is not associated with a specific orientation (Wolbers & Hegarty, 2010). Spatial knowledge can be acquired from different types of experience (Richardson, Montello, & Hegarty, 1999), such as by navigating in an environment or by reading a map. Thorndyke and Hayes-Roth (1982) postulated the existence of two mental representations of an environment: a survey representation, which is a mental bird's eye view of an environment obtained after learning it from a map; and a route representation, which is a ground level knowledge deriving from having navigated in an environment (Thorndyke & Hayes-Roth, 1982). Subsequent research demonstrated, however, that it is difficult to distinguish between route and survey representations obtained after learning from a given type of input (Montello, Waller, Hegarty, & Allen, 2004). For instance, Montello (1998) assumed that people acquire spatial information by integrating "units in more complex structures", i.e., that they start to develop metric and configural knowledge after a first exposure to a new environment, and then add to this knowledge on gaining further experience of it. Montello (1993) also proposed classifying spaces (i.e., spatial learning inputs) based on their scale, suggesting that spaces can be divided into figural, vista, environmental and geographical spaces.

i) Figural spaces are smaller than the learner’s body and visible from one point of view, such as pictures or small configurations of objects.

ii) Vista spaces are also visible from one point of view, but they are larger than the learner’s body, such as a room.

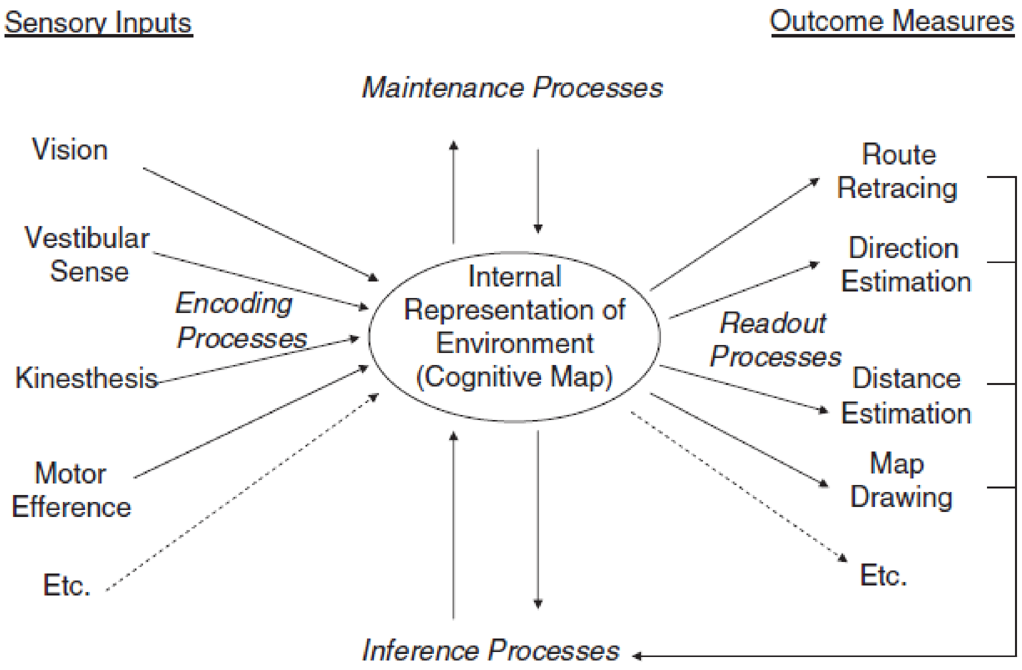
iii) Environmental spaces are larger still and demand locomotion in order to gain experience of them, such as buildings and cities.

iv) Geographical spaces are even larger and cannot be learned through locomotion, such as countries and continents.

According to Montello’s definition (1993), maps represent environments by means of pictures, so they should be considered as figural space inputs.

Another definition commonly used in spatial cognition studies focuses on the abilities implicit in learning spaces, distinguishing between small- and large-scale spatial abilities. Small-scale spatial abilities are used to mentally transform representations of objects (Hegarty et al., 2006), while large-scale abilities are used to learn environments and when navigating (Evans, 1980; Hegarty et al., 2006). Most of the early studies on spatial cognition considered these abilities as overlapping (the unitary model), assuming that small- and large-scale abilities reflected the same cognitive skills (e.g., Gärlin & Golledge, 1987)), but there is now support in the literature for a model partially dissociating the two. For example, Hegarty and colleagues (2006) analyzed the ability to configure an environment by administering several spatial recall tasks after participants had learned a route, and they found that this ability had cognitive processes in common with small-scale abilities, such as visuo-spatial abilities. Their model suggested that there are several experiences that can serve as input for acquiring spatial knowledge, and that the internal representations deriving from exposure to an environment can be tested by means of several tasks. Mental spatial representation cannot be measured directly. It has to be inferred from spatial task performance (Hegarty et al., 2006); and the cognitive processes involved in forming and using mental representations (maintenance and inference) should be taken into account as well. This model suggests the important influence of individual differences on large-scale spatial cognition. Figure 1.1. schematically shows the mental spatial representation processes proposed by Hegarty et al. (2006).

Figure 1.1. *Processes involved in constructing and using mental spatial representations (Hegarty et al., 2006)*



In large-scale environment learning there are therefore different factors that become sources of variability in the construction and use of mental spatial representations. As shown above, one such factor is the type of input: whether an environment is learned by really or virtually navigating therein, or from maps, or from spatial descriptions will influence the resulting mental spatial representation (Allen, 2003; Waller & Nadel, 2013). According to Richardson et al. (1999), looking at a map and navigating in an environment are the methods generally used to acquire spatial knowledge, although simulations of an environment, such as slides, videos or virtual environments are interesting to analyze too.

Another factor is the outcome measure used to test mental spatial representations (Hegarty et al., 2006). The mental spatial representation that an individual constructs after gaining experience of a new city or park from maps or navigation can be tested by means of a variety of tasks that may involve recalling the landmarks encountered and their relationships, or judging distances and directions. Different outcome measures give us a chance to analyze how information is stored and organized in memory (Golledge, 1999). Spatial recall tasks can differ in terms of the cognitive processes needed to complete them. For instance, to imagine pointing in the direction of locations that are not visible, i.e., to solve pointing tasks (also called judgments of relative directions; Shelton & McNamara,

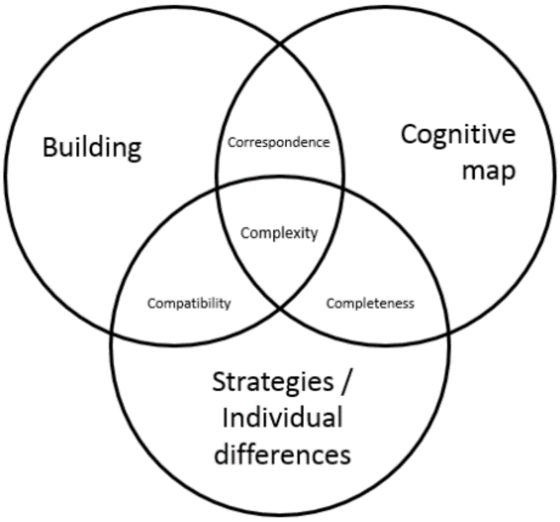
2001) involves using mental spatial representations and inferring positions with respect to a given heading. Map drawing, on the other hand, demands configurational knowledge, but less inference (Hegarty et al., 2006). The combined analysis of different inputs and spatial recall tasks is important too, because combinations of these external factors may modulate mental spatial representations differently.

Our understanding of the relationship between small- and large-scale abilities can be enriched by considering individual differences, which (like external factors such as the type of learning input or the type of task used in the recall phase) can influence the creation and use of mental spatial representations. In the complex setting of mental spatial representation processes, the analysis of individual factors has become a topic of growing interest (Shelton et al., 2013; Wolbers & Hegarty, 2010). These factors include age, sex, and individual visuo-spatial factors (such as visuo-spatial abilities and self-assessed spatial preferences), for instance.

It is particularly important to consider age because spatial performance is fundamental to any individual's self-sufficiency in later life (Wolbers & Hegarty, 2010). Age-related changes in spatial learning occur not only in pathological aging (Gazova et al., 2013), but also in normally-aging individuals (Klencklen et al., 2012; Moffat, 2009). Neurocognitive models have confirmed as much, demonstrating that the brain structures involved in spatial learning are vulnerable to aging (Klencklen et al., 2012; Lithfous, Dufour, & Després, 2013). Spatial learning and memory processes rely on the brain's regional networks (Maguire, 1998; Spiers & Barry, 2015; Wolbers & Wiener, 2014), with the hippocampus serving as the main hub (O'Keefe & Nadel, 1978). Hippocampal place cells are involved both in the formation of mental spatial representations (Bird & Burgess, 2008), and in their storage (Lithfous et al., 2013). Hence neurocognitive models support the importance of analyzing age-related changes in spatial memory (Postma & van der Ham, 2016), and aging models too. An aging model describes aging as a multidimensional and multidirectional stage of life (P. B. Baltes & Staudinger, 2000), when some abilities deteriorate over time, but some strengths remain that can help older adults to cope with these losses (Baltes & Baltes, 1990).

Individual differences in spatial learning (e.g., relating to age or visuo-spatial abilities) should be analyzed both separately and in combination. A model proposed by Carlson, Holscher, Shipley, and Dalton (2010), for instance, combined individuals' mental spatial representations with their visuo-spatial abilities (internal factors) and the spatial structure of the environment (an external factor), claiming that spatial tasks are managed by a simultaneous combination of these three aspects. Their model was applied to indoor wayfinding, but it is useful when considering how mental spatial representations (cognitive maps) can be influenced by the intersection between internal characteristics (e.g., visuo-spatial abilities) and external aspects (e.g., features of the environment). Figure 1.2. is a schematic representation of this model.

Figure 1.2. *Factors involved in navigation in buildings, as proposed by Carlson et al. (2010).*



What emerges from the proposed theoretical models is the importance of analyzing people’s mental spatial representations (Tolman, 1948; Wolbers & Hegarty, 2010), and how they are influenced by different types of input and the use of different spatial recall tasks (Hegarty et al., 2006; Montello, 1998), and their combination with individual differences (Carlson et al., 2010), and particularly the role of age (Klencklen et al., 2012; Lithfous et al., 2013; Moffat, 2009). Studies concerning age-related differences and the role of visuo-spatial factors in spatial learning are reviewed in the following paragraphs.

1.2. The role of age in mental spatial representation

Spatial learning is a complex matter. People can differ widely in terms of accuracy due to external factors (e.g., the source of spatial information, the type of task used to test the resulting mental representation), and to internal factors. Increasing attention has been paid to analyzing the latter (Waller & Nadel, 2013; Wolbers & Hegarty, 2010), and one of the most influential internal factors is unquestionably age. It is important to extend our theoretical knowledge of spatial learning to populations likely to be weaker in this cognitive area, such as the elderly. An impairment in this domain in older people can affect their ability to live safely and independently. Studies have clearly shown that spatial learning deteriorates from 60 years of age onwards, and this decline accelerates beyond the age of 70 (Barrash, 1994; Klencklen et al., 2012; Moffat, 2009). Spatial learning can be considered one of the fluid abilities that decline across the adult lifespan. According to the aging theory advanced by Horn and Cattell (1967), there is a distinction to be drawn between fluid and crystallized abilities: the decline in the former and preservation of the latter seen in older adults are an example of the multidimensionality of aging (Baltes & Staudinger, 2000).

Neurocognitive models support the need to study aging-related differences in spatial learning. The hippocampus and its network are particularly vulnerable to aging (Klencklen et al., 2012; Lithfous et al., 2013). Pathological aging conditions also point to the influence of age-related differences in spatial learning. For instance, spatial impairments develop already in the earliest stage of Alzheimer's disease (AD, see Gazova et al., 2012 for a review), in which topographical disorientation is one of the first symptoms (Iachini, Iavarone, Paolo Senese, Ruotolo, & Ruggiero, 2009; Moffat, 2009; Serino, Morganti, Di Stefano, & Riva, 2015).

Age-related differences in spatial learning have emerged in studies using different types of input, such as verbal spatial descriptions (e.g., Meneghetti, Borella, Muffato, et al., 2014), and visual inputs in the form of maps (e.g., Borella, Meneghetti, Muffato, & De Beni, 2015), or navigation (e.g., Taillade, N'Kaoua, & Sauzéon, 2016). Age-related differences in relation to the use of maps and route learning are discussed in the following paragraphs.

1.2.1. Age-related differences in map learning

Maps present spatial information allocentrically, based on an aerial view of the layout of an environment and canonical coordinates (north, south, east and west). Maps present spatial information configurationally. They are the method used to depict whole areas, and to show landmarks and paths connecting them (e.g., Richardson et al., 1999; Thorndyke & Hayes-Roth, 1982). According to Montello's classification (Montello, 1993), maps are figural sources that reproduce spaces on a scale smaller than the learner's own body. They are used as navigation tools and to assess individuals' ability to orient themselves in an environment – by asking people to study a map and then walk along a route they have learned, for instance (Allain et al., 2005; Salthouse & Siedlecki, 2007; Webber & Hansen, 2000; Wilkniss, Jones, Korol, Gold, & Manning, 1997). Maps can also be useful for analyzing cognitive processes involved in learning an arrangement of landmarks and constructing mental spatial representations (e.g., Coluccia, 2008; Coluccia, Bosco, & Brandimonte, 2007). Research has shown that, after learning from a map, older and younger adults fare equally well in tasks that retain the same configurational properties. These tasks may consist in graphically reproducing landmarks and their locations on paper (freehand map drawing tasks, e.g., Meneghetti, Borella, Grasso, & De Beni, 2012; Meneghetti, Fiore, Borella, & De Beni, 2011) or locating landmarks on a sketch of the environment seen on the map (sketch map tasks, e.g., Yamamoto & DeGirolamo, 2012). But when the spatial recall task involves a change of spatial format, older adults have more difficulty than younger adults (Salthouse & Siedlecki, 2007; Thomas, Bonura, & Taylor, 2012). This is the case, for instance, when people are asked to judge sentences about spatial relationships (e.g., Meneghetti, Borella, Gyselinck, & De Beni, 2012; Meneghetti, Muffato, Suitner, De Beni, & Borella, 2015), to judge directions, or to imagine adopting imaginary views (pointing tasks, e.g., Borella et al., 2015; Muffato, Della Giustina, Meneghetti, & De Beni, 2015). Older adults have particular difficulty in adopting a view counter-aligned with respect to the one previously learned (e.g., Aubrey, Li, & Dobbs, 1994), and generally in rotating the views they have memorized (e.g., Hartley et al., 2007).

To analyze age-related differences in map learning, it is consequently important to use different spatial tasks to test how individuals manage their spatial knowledge, by asking them to reproduce a configuration and to adopt different imaginary views, for instance. In everyday life, just as maps are a common source of learning, learning a route through navigation is a common experience, and another setting in which age-related differences may be an important factor to analyze.

1.2.2. Age-related differences in route learning from navigation

While people are navigating, they acquire information from a first-person perspective. The environment is experienced egocentrically through their body's movements (changes in direction detected by their vestibular sense, and in position detected by their proprioceptors), and the optic flow perceived by vision (Montello, 2005). The aging literature has generally demonstrated that older adults' performance is impaired in a variety of environment recall tasks, such as: returning to a starting point after being moved in a layout, as in the triangle completion task (Harris & Wolbers, 2012); learning a place by referring to visual cues, as assessed with the Morris water maze task (Moffat & Resnick, 2002); or learning routes by navigating in an environment (Barrash, 1994; Cushman, Stein, & Duffy, 2008; Gyselinck et al., 2013; Harris, Wiener, & Wolbers, 2012; Harris & Wolbers, 2014; Head & Isom, 2010; Iaria, Palermo, Committeri, & Barton, 2009; Jansen, Schmelter, & Heil, 2009; Kirasic, 1991, 2000; Lipman & Caplan, 1992; Lövdén, Schellenbach, Grossman-Hutter, Krüger, & Lindenberger, 2005; Moffat, Zonderman, & Resnick, 2001; Taillade et al., 2016; Uttl & Graf, 1993; Wiener, Kmecova, & de Condappa, 2012; Wilkniss et al., 1997; Zancada-Menendez et al., 2015; Zhong & Moffat, 2016). In particular, studies have shown that aging affects the ability to re-walk a previously-learned route (route repetition task; e.g., Barrash, 1994; Wilkniss et al., 1997). In a first study, Barrash (1994) observed that route repetition performance was worse in older than in young adults after learning a route at a medical center. If the task was repeated, however, then young-old adults (aged from 60 to 69 years old) performed as well as young adults, while those in their seventies continued to perform less well than the younger groups. Wilkniss et al. (1997) likewise found that older adults made more mistakes than younger people and took longer to complete a route repetition task after learning a route at a medical center. Participants also completed other spatial recall tasks, i.e., landmark recognition and map drawing. In the map drawing task, older adults made more mistakes than younger participants, even though they were able to recognize the landmarks equally well. The importance of using multiple tasks to shed light on route learning performance in aging was also evident in a study by Cushman et al. (2008), in which young and older adults learned a real route in a hospital lobby, then completed route repetition, landmark recall, landmark recognition, and photo location tasks. Their results indicated that older adults were less efficient than young adults when it came to recalling and placing landmarks in the right position on a sketch of the environment, while the two age groups performed equally well in the route repetition and landmark recognition tasks.

Taken together, these findings suggest that age-related differences become apparent in tasks that involve managing spatial knowledge (as in map drawing tasks because of the change of format), while there may or may not be differences in tasks with a format resembling that of the learning phase (such as route repetition and landmark recognition tasks).

Age-related differences have also been investigated considering more than one input at a time. Studies comparing more than one source of learning are discussed in the next section.

1.2.3. Age-related differences and comparisons between learning inputs

Some studies have compared two learning inputs with a view to analyzing age-related differences. For instance, map learning has been compared with both spatial description learning (Meneghetti, Borella, Grasso, et al., 2012), and route learning (e.g., Yamamoto & DeGirolamo, 2012). In both cases, map learning was found better preserved than the other learning input. Yamamoto and De Girolamo (2012) asked participants to learn the locations of landmarks by seeing an aerial view (a map) and by navigating. 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 map reading skills are better preserved with aging than exploratory navigation skills. To support their findings, they reported that neuroimaging findings demonstrate that the medial temporal lobe - implicated in navigation, but not in map reading - is susceptible to aging (Yamamoto & DeGirolamo, 2012). Their study suffers from the limitation that they tested participants' recall of the environment with a spatial test (the sketch map task) that maintained the same format as learning from an aerial view, so a change of point of view was only needed in the case of learning from navigation. In map drawing or sketch map tasks (Blades, 1990; Rovine & Weisman, 1989), the visuo-spatial format and the need to locate landmarks in relation to one another are consistent with learning from a map, but not with learning from navigation. Map learning can therefore make it easier for older people to form mental spatial representations, avoiding the difficulties of switching between a first-person view and a map view and of representing information allocentrically (Ruggiero, D'Errico, & Iachini, 2016). On the other hand, mentally switching viewpoints becomes more difficult with aging and this impairs an individual's navigation skills (Devlin & Wilson, 2010). Orientation specificity, or the alignment effect (Evans & Pezdek, 1980; Levine, 1982), is also inherent in map learning because spatial knowledge is acquired from a single point of view, whereas navigation allows for multiple viewpoints to be experienced, and judgments of direction after navigation may be less dependent on a particular orientation (McNamara, 2013). The comparison between learning inputs and orientation specificity remains an open issue in relation to aging.

In short, age-related differences emerge when we compare people's ability to learn routes from maps vis-à-vis navigation, but these differences are influenced by the type of input used in the learning phase and by the spatial recall tasks used to test this learning. Other internal factors, as well as age, can influence an individual's mental spatial representations, including their visuo-spatial characteristics, as discussed in the next section.

1.3. The role of visuo-spatial factors in spatial learning

It is important to consider other individual differences, along with age, that can influence a person's mental spatial representations. People's visuo-spatial factors are of particular interest because research has demonstrated their involvement in spatial learning. These factors include all the variables relating to visuo-spatial aspects, such as visuo-spatial working memory (VSWM), visuo-spatial abilities, and 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). It has been shown to influence route learning (Garden, Cornoldi, & Logie, 2002; Labate, Pazzaglia, & Hegarty, 2014), and map learning (e.g., Coluccia et al., 2007) in young adults, and there is prominent evidence of its role in older adults' spatial learning too (e.g., Borella et al., 2015).

Visuo-spatial abilities are higher-level cognitive skills used to generate, retain and manage abstract visual images (Lohman, 1988), and numerous sub-abilities can be distinguished (reviewed in Hegarty & Waller, 2005; Linn & Petersen, 1985). Uttal and collaborators (2013) proposed a classification based on two dimensions, one dynamic vs. static (i.e., the active manipulation vs. the perception of objects), and one intrinsic vs. extrinsic. Dynamic abilities have been the most studied. The ability to mentally rotate 2D or 3D objects (as measured with the Mental Rotations Test, MRT; Vandenberg & Kuse, 1978) is an example of a dynamic-intrinsic ability, while the ability to imagine to take different perspectives (as measured with the Object Perspective-Taking test, OPT; Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001) is a dynamic-extrinsic ability. Like VSWM, these abilities have been found fundamental to spatial learning (e.g., Fields & Shelton, 2006; Hegarty et al., 2006; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). For instance, Hegarty et al. (2006) suggested that visuo-spatial abilities and self-reported sense of direction predict large-scale learning. They found visuo-spatial abilities more closely related to learning from media (such as a video) than to learning from direct experience (navigation), while the opposite applied to self-reported sense of direction (Hegarty et al., 2006). Either way, these individual factors have demonstrated their relevance in spatial learning, and recent findings have extended this knowledge to aging too (Meneghetti, Borella, Muffato, et al., 2014). The main findings relating to the role of visuo-spatial characteristics in aging are discussed in the following paragraphs.

1.3.1. Visuo-spatial factors and older adults' spatial learning

Preliminary but promising evidence shows that individual visuo-spatial factors, and especially visuo-spatial abilities, can sometimes override age-related differences between young and older adults.

First, it is worth mentioning that both VSWM and visuo-spatial abilities have been shown to decline with aging (Borella, Meneghetti, Ronconi, & De Beni, 2014; Techentin, Voyer, & Voyer, 2014). Rotation abilities in particular seem to deteriorate with a linear trend from youth to old age, while perspective-taking abilities start to become impaired from about age fifty onwards (Borella et al., 2014).

Recent evidence suggests that these abilities nonetheless retain a role in mental spatial representation in the more elderly, as demonstrated in the case of spatial description learning, for instance (Meneghetti, Borella, Muffato, et al., 2014). As for map learning, there is still a paucity of knowledge, but there have been some promising reports of VSWM (Borella et al., 2015) and visuo-spatial rotation abilities (De Beni, Pazzaglia, & Gardini, 2006; Meneghetti et al., 2011) positively affecting older people's spatial recall performance. In particular, Borella et al. (2015) found a correlation between VSWM and pointing task performance after participants had learned an environment from maps, while also demonstrating the increasing orientation dependence of mental spatial representations with aging.

The results are inconsistent as concerns route learning from navigation. Kirasic (2000) found an important role for individual visuo-spatial factors in predicting environmental performance. She assessed spatial visualization and rotation abilities (using a psychometric test battery) in a sample of young and older adults, then asked them to learn the layout of a supermarket by walking around in it, led by the experimenter. Several spatial recall tasks were then administered to test their wayfinding abilities (with a task that involved participants findings a list of items) and their configural knowledge (with scene recognition, distance ranking, and map placement tasks). The results indicated that wayfinding performance was affected by recall of the layout, which was influenced by age. In particular, age affected configural knowledge both directly and through the mediation of an individual's visuo-spatial abilities. This means that it is not only age that we need to take into account when analyzing people's mental spatial representations. On the other hand, Taillade et al. (2016) found no correlation between visuo-spatial abilities and route learning performance in aging. These authors asked participants to learn a route in a city and then to complete a route repetition task, a task that involved placing pictures of landmarks in their order of appearance, and a route drawing task. An age-related decline was observed for all the tasks, but cognitive performance, including VSWM (measured with the backward Corsi task; Wechsler, 1997) and rotation ability (with MRT; Vandenberg & Kuse, 1978) had no effect on the older adults' spatial task performance. The authors attributed this to methodological issues, such as their use of a composite score, which may have masked the effects of single variables liable to decline with age. Their study (Taillade et al., 2016) confirms the importance of considering individual visuo-spatial factors when analyzing mental spatial representations, however. Mitolo et al. (2015) compared a sample of all old adults in map and route learning, and suggested that their visuo-spatial abilities predicted their map learning, while their VSWM (measured with the Corsi task) predicted their route learning. Finally, as regards environmental knowledge in a broader sense, Meneghetti, Borella, Pastore, and De Beni (2014) found that the ability to orient oneself using cardinal points is affected by age (considering the whole adult lifespan, from 20 to 91 years old) through the mediation of VSWM and visuo-spatial abilities. The authors again concluded that it is important to consider individual visuo-spatial factors when examining spatial knowledge, even in very old people (Meneghetti, Borella, Pastore, et al., 2014).

In short, visuo-spatial factors influence people's mental spatial representations and, though their abilities decline with age, they still have a role in sustaining their spatial recall performance, even in the elderly. It is therefore essential to consider these individual visuo-spatial characteristics in combination with different types of environmental knowledge input and different spatial recall tasks, in order to elucidate spatial performance at different ages, especially since the contemporary role of different internal and external factors has rarely been considered.

The literature reviewed in these paragraphs is summarized in Table 1.1, showing the main results of studies using map learning, route learning and combinations of inputs, the age groups involved, and any individual visuo-spatial factors considered.

Table 1.1. *Summary of studies on the role of age and visuo-spatial factors in spatial learning (listed by type of learning input and in chronological order).*

Type of learning input	**Study**	**Environment**	**Sample**	**Spatial recall tasks**	**Visuo-spatial factors**	**Main results**
Map learning	Aubrey et al., 1994	You-are-here maps	26 young (*M* age = 26) vs. 26 old (*M* age = 71)	Pointing task	/	Age-related differences only for counter-aligned, not for aligned maps.
Map learning	Webber & Hansen, 2000	Street maps	15 young (*M* = 36.1 years) vs. 15 old (*M* = 69.3 years)	Planning routes and giving directions	/	Older adults formed two groups, one more and the other less competent.
Map learning	Allain et al., 2005	Zoo map	16 young (19–50 years) vs. 18 old (72–97 years)	Completing routes	/	Age-related differences were found. The route planning process comprises formulation and execution levels.
Map learning	De Beni et al., 2006 [exp 2]	Fictitious city map	22 young (20-26 years) vs. 24 old (67-84 years)	Map drawing task Pointing task	Groups matched for MRT	Older adults performed better than young adults matched for MRT in the pointing task, but not in the map drawing task.
Map learning	Salthouse & Siedlecki, 2007	Zoo maps	328 participants (18-93 years old)	Selecting the best route to points of interest	[Cognitive ability test: fluid ability, episodic memory, perceptual speed]	The effect of aging was moderate, and accelerated beyond sixty years old. Performance correlated with cognitive abilities.
Map learning	Meneghetti et al., 2011	Fictitious city map	30 young (20-30 years) vs. 30 old (60-72 years)	Map drawing task Pointing task	Visuo-spatial ability tasks SDSR scale	Age-related differences were found for both map drawing task and pointing task. Correlations between performance and visuo-spatial factors were found only for pointing tasks in the elderly.

Type of learning input	**Study**	**Environment**	**Sample**	**Spatial recall tasks**	**Visuo-spatial factors**	**Main results**
Map learning	Thomas et al., 2012	Fictitious city map with semantically categorizable landmarks	Exp 1: 24 young (*M* =19.2, *SD* =1.5) vs. 23 old (*M* = 74.4, *SD* = 6.2) Exp 2: 99 old (*M* = 76.5, *SD* = 5.2) in different conditions based on instructions	Free landmark recall and distance estimation tasks.	/	In exp 1: older adults recalled fewer landmarks than young adults. The young underestimated the distance between categorized landmarks more than older adults. In exp 2: older adults improved their performance when given instructions on how to use semantic features.
Map learning	Borella et al., 2015	Fictitious environments maps	Exp 1: 19 young (20-30 years) vs. 19 young-old (60-74 years) Exp 2: 19 young (20-30 years) vs. 19 young–old (60-74 years) vs. 19 old-old (75-84 years).	Pointing and map drawing tasks Exp 2: in conditions with or without a map	Exp 2: VSWM (Visual Pattern and Puzzle tests)	Young performed better than old in both tasks. Older adults made more opposite quadrant errors in the pointing task. In Exp 2: having the map available improved all participants' performance. VSWM correlated with the performance.
Map learning	Muffato et al., 2015	Familiar home town vs. fictitious environment maps	19 young (18-23 years) vs. 19 young–old (60-74 years)	Pointing task	VSWM and visuo-spatial abilities (sMRT and sOPT)	Young performed better than older adults in pointing task after learning a unfamiliar map. Older adults did better in familiar than in unfamiliar environments.
Map learning	Meneghetti et al., 2015	Fictitious environments maps	34 young (20-30 years) vs. 34 young-old (60-74 years) vs. 34 old-old (75-84 years).	Map drawing, pointing and verification tasks	/	Older adults performed less well than young in all spatial tasks. Old-old were worse than young-old only in the pointing task. Perceived stereotype threat mediated the relatiom between age and map drawing performance.

Type of learning input	**Study**	**Environment**	**Sample**	**Spatial recall tasks**	**Visuo-spatial factors**	**Main results**
Free exploration	Kirasic, 1991	Familiar and unfamiliar supermarkets	20 young (21-33 years old) vs. 20 old (62-86 years old)	Scene recognition, distance ranking, completing routes, map placement. Behavior recorded while walking.	Spatial visualization abilities (Form Board test, Cube comparison, Building Memory test)	Age-related differences in scene recognition. In ranking distance and completing routes, older adults did better in familiar than in unfamiliar environments. Weak correlations with visuo-spatial abilities.
Free exploration	Uttl & Graf, 1993	Art exhibition	302 from 15 to 74 years old	Map and relocation tasks	/	Age-related decline in spatial memory performance begins in the sixth decade of life.
Route learning	Barrash, 1994	Medical center	80 from 18 to 78 years old	Route repetition task (three repeated trials)	/	Decline became evident from 60 years old onwards, and more pronounced from 70 years old.
Route learning	Lipman & Caplan, 1992	Route in Washington (presented by means of slides)	54 young (25-40 years) vs. 53 old (60-75 years). 3 conditions: no aid, map as aid, diagram as aid	Free recall of landmarks, turns and route configuration.	Block and similarities from WAIS-R. Sense of Direction	Young performed better than older adults. Older males benefited from map as aid. Block task had no effect.
Route learning	Wilkniss et al., 1997	Medical center. Conditions: No- map task vs. Map task	25 young (18-21 years) vs. 25 old (59-89 years)	Route repetition, landmark recognition, sequential ordering, and layout representation tasks.	/	Older adults performed less well than young in route repetition, landmark ordering and map placement tasks, while they were equally good at recognizing landmarks.

Type of learning input	**Study**	**Environment**	**Sample**	**Spatial recall tasks**	**Visuo-spatial factors**	**Main results**
Free exploration	Kirasic, 2000	Supermarket	120 young (18-25 years) vs. 120 old (60 to 84 years)	Route execution task; environment layout tasks: scene recognition, distance ranking, map placement.	Spatial ability tests	The best-fitting model showed that age-related differences in environment layout knowledge were significantly mediated by a single ability factor. Environment layout knowledge mediated between spatial ability factor and wayfinding.
Route learning	Moffat et al., 2001	Virtual maze	133 participants from 20 to 91 years old	Remembering the route to the goal	Benton Visual Retention Test, Card Rotations Test, Digit Span Forward and Backward and the Similarities (WAIS-R)	Older adults took longer and walked a longer distance to reach the goal. Mental rotation, verbal and visual memory positively correlated with navigation task performance.
Route learning	Cushman et al., 2008	Medical center lobby (real and virtual)	35 young (*M* age = 23.18, *SD* = 0.72) vs. 26 old (*M* age = 73.40, *SD* = 0.80) [vs. 12 MCI vs. 14 AD]	Route repetition, free recall, self-orientation, route drawing, landmark recall, recognizing photographs, locating photographs and videos	/	Normal older adults had greater difficulties than young adults in self-orientation and scene location tests.
Free exploration	Iaria et al., 2009	Virtual city	30 young (19-30 years) vs. 25 old (50-69 years)	Reaching the location of given landmarks	/	Older adults took longer and were less efficient than young adults in using a mental map for orientation
Free exploration and route learning	Head & Isom, 2010	Virtual maze	Wayfinding condition: 16 young (18-22 years) vs. 31 old (56-83 years) Route learning: 13 young (18-22 years) vs. 32 old (56-88 years)	Landmark recall, scene recognition, arranging landmarks by order of appearance and location tasks	/	Age-related differences were found: for wayfinding, in landmark recall and scene recognition tasks; for route learning, in temporal ordering of landmarks; with deficits in configural knowledge in both conditions.

Type of learning input	**Study**	**Environment**	**Sample**	**Spatial recall tasks**	**Visuo-spatial factors**	**Main results**
Free exploration	Jansen et al., 2009	Virtual maze	20 young (20-30 years) vs. 20 middle-aged adults (40-50 years) vs. 20 old (60–70 years).	Route repetition without landmarks. Second learning phase and route repetition. Landmark recall. Map drawing test.	/	Older adults did worse in all tasks. The middle-aged performed worse than young but better than old in the first route repetition and map drawing. After second learning, however, there were no age-related differences.
Route learning	Wiener et al., 2012	Virtual maze	20 young (25-30 years) vs. 20 old (61-85 years)	Route repetition, route retracing, the direction required to continue along the route, and landmark sequence tasks	/	Age-related deficits in all tasks. Older adults performed worse in route retracing than in route repetition, while young did not show this difference.
Route learning	Gyselinck et al., 2013	Virtual city	34 young (M = 20.82, SD = 1.38) vs. 30 middle-aged (M = 56.17, SD = 3.29) with good spatial abilities	Recognition, location and verification tasks	/	Groups were similar in recognition and verification tasks (direct sentences), and different in location and indirect verification tasks.
Free exploration	Harris & Wolbers, 2014	Virtual city	25 young (18-29 years) vs. 25 old (61-79 years)	Shortcut task	VSWM (Corsi)	Large age-related differences in shortcut task. Corsi did not correlate with shortcut task performance.
Route learning	Zancada-Menendez et al., 2015	Virtual maze	20 young (9–30 years) vs. 20 middle (31–55 years) vs. 20 old (56–80 years)	Route repetition, order of appearance of landmarks	[Corsi task]	Older adults performed worse than young and middle-aged adults. Constantly updating spatial information entails a great effort at all ages.

Type of learning input	Study	Environment	Sample	Spatial recall tasks	Visuo-spatial factors	Main results
Route learning	Taillade et al., 2016	A district in Bordeaux (real and virtual)	32 young (*M* age = 22.65, *SD* = 3.29) vs. 32 old (*M* age = 68.58, *SD* = 6.13).	Route repetition, map drawing, picture classification tasks	Visuo-spatial abilities (Corsi, MRT). Benton visual memory test, trial making test, Raven's matrices test. Self-report: SBSOD	Older adults performed worse in all spatial recall tasks. Spatial abilities had a mediating effect on the relationship between actual and self-assessed navigation performance, but only in young adults.
Free exploration	Zhong & Moffat, 2016	Virtual maze	58 young (18-38 years), 29 middle-aged (51-64 years) and 27 older adults (65-90 years)	Finding a goal (navigation errors), recognizing landmarks, associating directions with landmarks.	Card rotation test	Older adults performed worse than young adults in navigation and associating correct heading directions with critical and non-critical landmarks. Card rotation accuracy correlated negatively with navigation errors in older adults.
Map learning vs. description learning	Meneghetti, Borella, Grasso, et al., 2012	Fictitious city	60 young (*M*= 24 years, *SD*=2.55) and 60 old (*M*= 63 years (*SD*= 3.73)	Map drawing task Pointing task	Cattell test Mental Rotations Test	Young adults performed better than older adults in description learning, but the two groups did not differ in map learning. Correlations between variables were found.
Map vs. route learning	Yamamoto & DeGirolamo, 2012	Fictitious city	24 young (18–33 years) vs. 24 old (60–80 years)	Location task	/	Older adults performed worse than young in learning through navigation, but the two groups did not differ in learning from maps.
Map vs. route learning	Mitolo et al., 2015	Fictitious city map; 5x5 matrix for route learning	90 old (57-90 years)	Map drawing task (after map learning) Route reproduction (after route learning)	Corsi, Visual Pattern Test (VPT), Visuo-spatial ability tests, SOD-Q, Anxiety-Q and Efficacy-Q.	Visuo-spatial ability tests predicted map learning; Corsi predicted map and route learning; and VPT had a direct effect on route learning. Map learning had a direct effect on Efficacy-Q and route learning on SOD-Q and Anxiety-Q. There were also significant indirect effects of Corsi and VPT on questionnaires.

2. Study 1.

Map learning in young, young-old and old-old: the role of the type of task and visuo-spatial factors

2.1. Rationale and aims of the study

In Study 1[1] we used a map as source of information to elucidate which features of spatial mental representation are preserved or liable to age-related decline. Maps are a figural and allocentrically-based modality for acquiring spatial information.

The first theoretical premise of the study is that maps are sensitive in detecting age-related impairments in spatial learning (Klencklen et al., 2012; Moffat et al., 2001; Serino, Cipresso, Morganti, & Riva, 2014). Age-related differences emerge, however, only in some cases. When participants recall is tested with allocentric-based task, such as map drawing results are inconsistent: some studies reported similar performance in young and older adults (e.g., Meneghetti, Borella, Grasso, et al., 2012; Yamamoto & DeGirolamo, 2012), while others found an impaired performance in older adults (e.g., Meneghetti et al., 2011, 2015; Wilkniss et al., 1997). When participants are required to solve spatial inferential tasks (e.g., imagine adopting new views, as in pointing task), age-related differences are more clearly identifiable (Borella et al., 2015; Meneghetti et al., 2015). Thus, we tested participants' spatial performance after map learning using different types of task that involved configurational reproductions and the adoption of different imaginary views within the configuration. This by comparing three age groups: young and third and fourth age groups. Few studies that have investigated spatial learning in late adulthood have shown an increased impairment in the fourth age group (Borella et al., 2015; Meneghetti et al., 2015; Ruggiero et al., 2016).

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[1] Study 1 have been described in Meneghetti, Muffato, Borella, & De Beni (under revision)

A second theoretical premise is that individual visuo-spatial factors (such as VSWM and rotation abilities) might support spatial learning in all age groups (e.g., Meneghetti, Borella, Pastore, et al., 2014). Other individual factors are strategies people report using to learn spatial information (Stieff, Dixon, Ryu, Kumi, & Hegarty, 2014). For instance, it was found that young adults using survey (i.e., imagining viewing the layout from the air) and route (i.e., imagining that they were inside the layout) strategies benefited in spatial recall, while using a verbal strategy (i.e., repetition) was not useful (Meneghetti, Ronconi, Pazzaglia, & De Beni, 2014).

Thus, analyzing different self-reported strategy use when learning a map broaden the variety of individual visuo-spatial factors to consider in aging studies too.

Taking these aspects together, Study 1 aimed to examine age-related differences between young, young-old and old-old adults' map learning in relation to individual visuo-spatial factors. Participants were first asked to perform a series of visuo-spatial tasks. Then they studied an outdoor map of a Botanical Garden. They performed a series of spatial recall tasks: the pointing task (i.e., an inferential task), and two graphical reproduction tasks (freehand map drawing and a sketch map tasks). Participants' self-reported use of visuo-spatial strategies while studying the map were also recorded, given the influence of self-reported visuo-spatial strategies on spatial learning (Meneghetti, Ronconi, et al., 2014).

Our research hypotheses were as follows:

i) *Map recall in the three age groups*. We expected that age-related differences might depend on the recall tasks used. Concerning freehand map drawing task, we expected age-related differences, and in particular the old-old performing worse than the young-old. Freely placing landmarks in the layout is known to suffer an accentuated decline in advanced old age (Meneghetti, Borella, Muffato, et al., 2014). Moreover this task involves actively reproducing landmarks and their locations, even if it is allocentrically-based as the input (the map) used in the learning phase. Concerning the sketch map task, we expected any age-related differences to be attenuated because the task provides cues, i.e., participants are given the layout and the list of landmarks (Yamamoto & DeGirolamo, 2012). Concerning the pointing task, we expected to find age-related differences because of greater difficulty in adopting imaginary positions in aging (Harris et al., 2012).

Moreover, we expected both young-old and old-old to have particular impairments with counter-aligned position respect to the ones adopted during the learning phase (Aubrey et al., 1994; Borella et al., 2015).

ii) *Map learning and visuo-spatial factors.* We expected individual visuo-spatial factors to influence map learning, with a stronger involvement for more demanding tasks (Meneghetti, Borella, Muffato, et al., 2014). Freehand map drawing and pointing tasks accuracy may be influenced by individual visuo-spatial abilities and by self-reported visuo-spatial strategy use (Meneghetti, Ronconi, et al., 2014). In sketch map task, individual factors should be less prominent.

2.2. Method

2.2.1. Participants

The study involved 40 young adults (24 to 34 years old; 17 females), 40 young-old (65 to 74 years old; 17 females) and 40 old-old (75 to 86 years old; 17 females) for a total of 120 participants. There was no difference in the number of males and female in each group. All participants were volunteers recruited by word of mouth. Our inclusion criteria were: Italian mother tongue, and for the older group living independently. None of the participants had worked in jobs requiring navigational skills (e.g., Kozhevnikov, Kosslyn, & Shephard, 2005). The following exclusion criteria were adopted: a history of psychiatric or neurological diseases, use of benzodiazepines in previous months, symptomatic cardiovascular conditions, breathing problems, diseases capable of causing cognitive impairments, visual, auditory and/or motor impairments (Crook et al., 1986), as established from a semi-structured interview; familiarity with the botanical garden in Padua (Italy); and a score of more than 27 in the MMSE (Folstein, Folstein, & McHugh, 1975) for older participants. The age groups did not differ in years of education ($F < 1$, $p = .24$). Moreover, the three age groups did not differ in their crystallized abilities ($F < 1$, $p = .58$) measured using the WAIS vocabulary subtest (Wechsler, 1981). See Table 2.1. for participants' characteristics.

Table 2.1. *Means (M) and standard deviations (SD) of participants' characteristics.*

	Young adults (*N* = 40)		Young-old adults (*N* = 40)		Old-old adults (*N* = 40)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age	28.15	2.57	68.90	2.92	78.18	3.48
Education	13.35	2.24	12.48	3.52	12.20	3.53
Vocabulary	41.25	10.83	42.70	10.47	40.15	11.60

2.2.2. Materials

2.2.2.1. Session 1: visuo-spatial tasks

Jigsaw Puzzle Test (JPT, De Beni, Borella, Carretti, Marigo, & Nava, 2008). This VSWM task (adapted from Richardson & Vecchi, 2002) consists in solving up to 27 puzzles by mentally recomposing the pieces, without actually moving them. It is powerful and sensitive for investigating active elaboration component of VSWM, especially in older people (Richardson & Vecchi, 2002). Each puzzle represents a common, highly familiar object (e.g., an iron, a bicycle; from Snodgrass & Vanderwart, 1980). The picture is shown for two seconds, then the same object is shown broken down into numbered, randomly-arranged (from 2 to 10) pieces. Participants are asked to solve the puzzle by indicating the number of each piece in the appropriate position in an answer grid, without 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 score correspond to the sum of the three most complex correctly-solved puzzles (max. 29).

Short Mental Rotations Test (sMRT, De Beni, Meneghetti, Fiore, Gava, & Borella, 2014; adapted from Vandenberg & Kuse, 1978). This task measures visuo-spatial rotation ability. Each item is composed of 3D assemblies of cubes: one target and four options. The task consists in finding two of four objects that match the target object in a rotated position (10 items; time limit 5 minutes). The score correspond to the number of correct answers (max. 10).

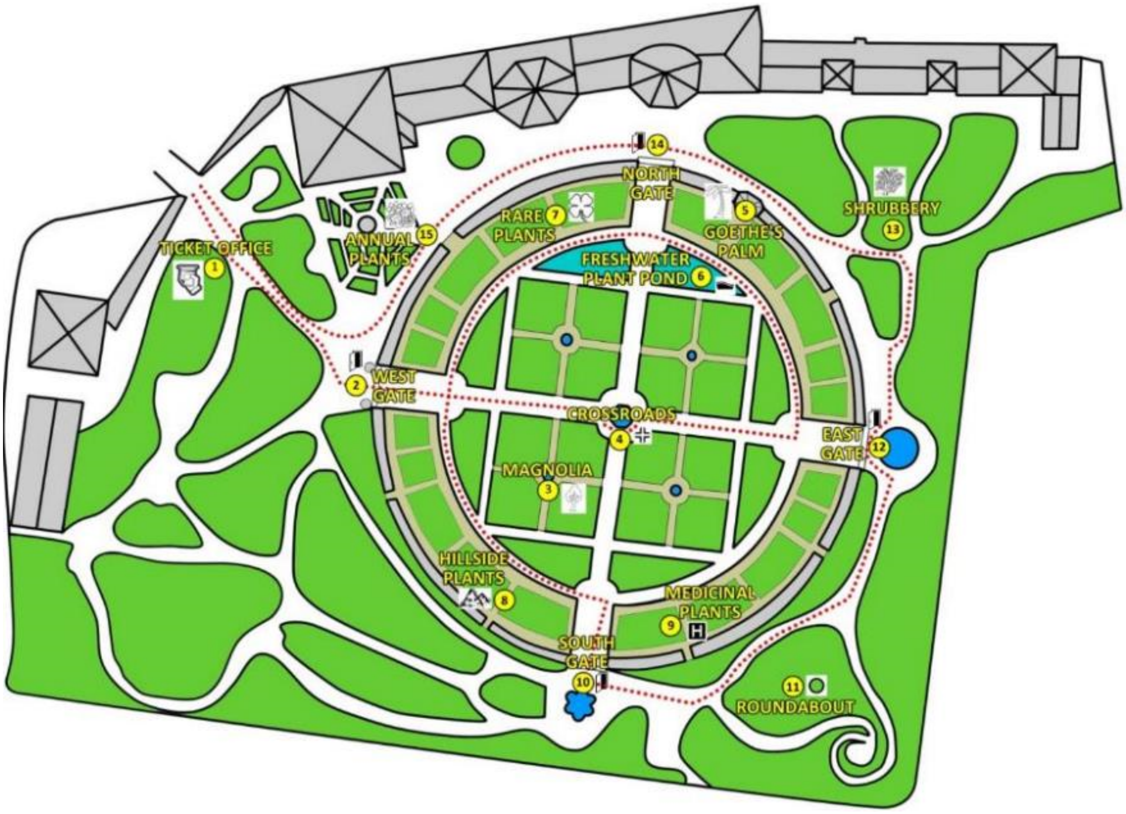
Short Object Perspective Test (sOPT, De Beni et al., 2014; adapted from Kozhevnikov & Hegarty, 2001). This task measures visuo-spatial perspective-taking ability. Participants are shown a layout on which seven objects are arranged; this layout remains available, in front of the participant during the task. The task involves imagining standing at one object, facing another, and pointing in the direction of a third. The direction of the object is indicated by drawing an arrow from the center to the perimeter of the circle (6 items; time limit 5 minutes). The score correspond to the mean absolute degrees of error, calculated considering the angular difference between the correct answer and the answer given (max. 180°).

2.2.2.2. Session 2

2.2.2.2.1. Learning phase: botanical garden map.

The map reproduces a botanical garden on an A4 paper. It is a 1:7 scale map of a botanical garden located in Padova (Italy). The botanical garden map comprises 15 landmarks, each identified by its name, a corresponding icon and a sequential number along a path marked in red (see Figure 2.1.). Four landmarks coincide with the cardinal points: the north, south, east and west gates of a circular wall located in the botanical garden. There is also a point in the middle of the garden where the two main paths –

Figure 2.1. *The map used in the learning phase in Study 1.*



starting from the entrances of the wall – cross (1 landmark). Another 10 landmarks are identified in the garden: annual plants, Goethe’s palm, hillside plants, magnolia, medicinal plants, pond, rare plants, roundabout, shrubbery, and ticket office (inside and outside the circular wall).

2.2.2.2.2. Retrieval phase

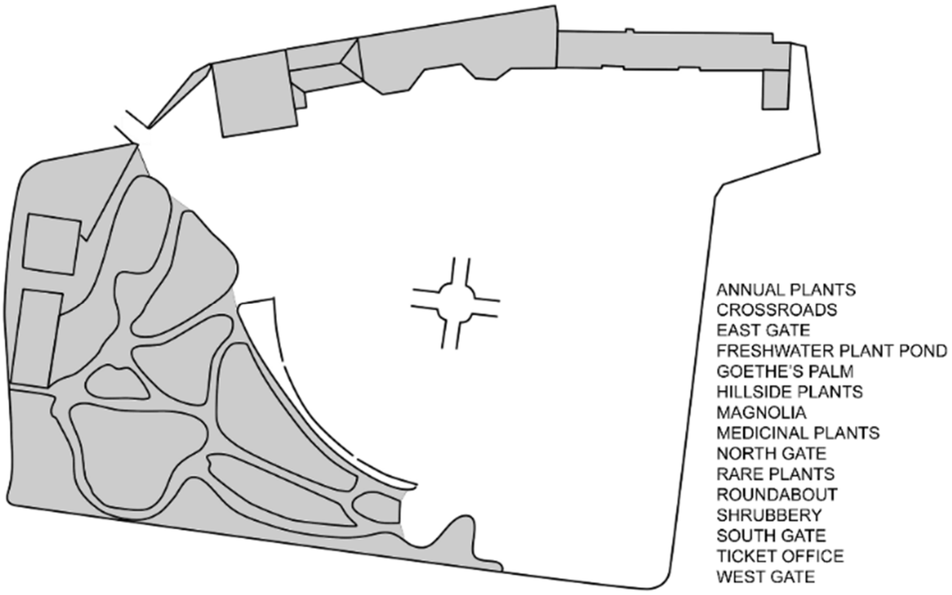
Strategy use scale. Strategies that can be used to learn from a map are assessed using a questionnaire (adapted from Meneghetti, Ronconi, et al., 2014). The strategy are: i) a route strategy, which focuses on a path seen from a person’s point of view (e.g., “I learned the path as if I were walking along it”); ii) a survey strategy focusing on a bird’s eye view of the environment (e.g., “I visualized the whole layout of the Botanical Garden”); iii) a verbal strategy based on words repetition (e.g., “I repeated the names of the landmarks”). Two items for each strategy are prepared. For each item, strategy use was rated using a Likert scale from 1 (not at all) to 5 (very much) and for each strategy the mean was calculated.

Freehand map drawing. The task consists in freely reproducing the map on a blank sheet of A4 paper, i.e., participants have to draw the environment and the landmarks they recall as accurately as possible.

Sketch map task. The task consists in locating the landmarks, listed in alphabetical order, on a sheet of A4 paper depicting a sketch map. The sketch map shows a skeletal structure of the botanical garden (see Figure 2.2.). Participants were instructed to place all the listed landmarks on the sketch map.

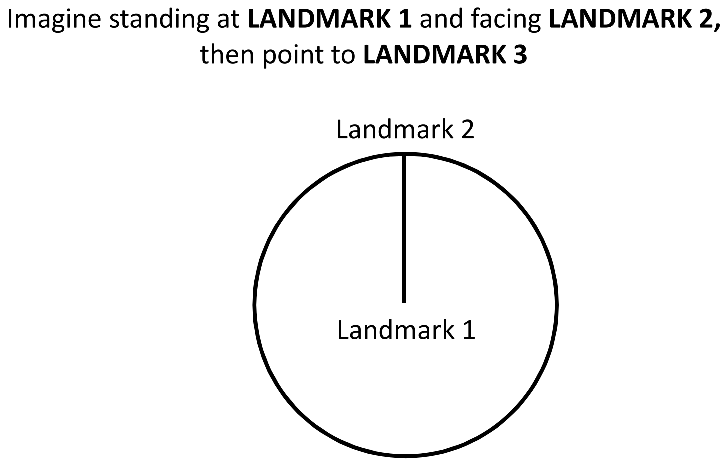
For the freehand map drawing and sketch map tasks, each map was scored using the Gardony Map Drawing Analyzer (GMDA, Gardony, Taylor, & Brunyé, 2016), an open-source software. As a measure of global map recall accuracy, it was used the Square Root of the Canonical Organization (SQRT-CO), a GMDA-unique measure proposed by Gardony et al. (2016) that compares the locations of landmarks relative to all the other landmarks with the Cartesian coordinates of the target layout (the map). Any missing landmarks (i.e., landmarks not placed in the drawing) disrupt accuracy. Thus, it is a sensitive measure of the global accuracy of the landmarks’ position and relationship to one another. The score ranged from 0 to 1, where higher scores indicate more accurate landmark positioning (for details see Gardony et al., 2016; Meneghetti, Muffato, Varotto, & De Beni, 2016). The number of landmarks missing was also considered as a measure of memory impairment; it is a measure that show a strong negative correlation with SQRT-CO (Gardony et al., 2016).

Figure 2.2. *Sketch map task.*



Pointing task. The task requires that participants imagine standing at a given landmark on the map, facing another landmark and pointing to a third. For each item, the sentence is written at the top of the page. The answer is given in a circle below, where the center of the circle represents the place where respondents imagine standing, an arrow points upwards to indicate the direction in which they face, and they must draw another arrow outwards from the center of the circle with its tip pointing in the direction of the target landmark (see Figure 2.3.). Two items are administered for familiarization purposes (feedback on the correct answer is provided). Then, 12 items are presented in random order. Six items involve adopting an aligned view with the one adopted in the learning phase (e.g., “Imagine standing at the East gate and facing the Shrubbery, then point to the North gate”). Other six items involve adopting a counter-aligned view (i.e., imagining rotating through 180°; e.g., “Image standing at the Shrubbery and facing the East gate, then point to the North gate”). For scoring purpose, the minimum difference in the absolute angle between each participant’s arrow and the right direction was calculated for each item. Then the mean pointing errors were computed for the aligned and counter-aligned items using circular statistics (see Borella et al., 2015 for details).

Figure 2.3. *Pointing task: example of item presentation.*



2.2.3. Procedure

Participants were tested individually in two sessions lasting a total of two hours, in a quiet room at a recreation center. After giving their consent by signing a form, in the first session, the older participants completed the MMSE, and all participants completed the Vocabulary test and the visuo-spatial tasks (JPT, sMRT and sOPT) in a balanced order across participants. In the second session, participants studied the map of the Botanical Garden for up to 5 minutes. They answered the strategy use questionnaire and then they completed the freehand map drawing, the sketch map and the pointing tasks.

2.3. Results

The statistical analyses were conducted using both IBM SPSS Statistics 22 software and R. In the following sections, when a post hoc comparison is described, Bonferroni's correction was used.

2.3.1. Spatial recall tasks in the three age groups

Descriptive statistics for number of missing landmarks and accuracy (SQRT-CO) of the map drawing and sketch map tasks, and aligned and counter-aligned pointing are presented in Table 2.2.

Table 2.2. *Means (M) and standard deviations (SD) for the freehand map drawing, sketch map task and pointing task by age group.*

		Young adults		Young-old adults		Old-old adults	
		M	*SD*	*M*	*SD*	*M*	*SD*
Freehand map drawing task	Number of missing landmarks (0-15)	3.13	2.55	5.38	2.49	6.60	2.05
	Accuracy (0-1)	.74	.17	.57	.16	.50	.14
Sketch map task	Number of missing landmarks (0-15)	0.73	1.69	0.63	1.58	3.48	3.41
	Accuracy (0-1)	.89	.13	.86	.11	.69	.20
Pointing task	Aligned (max.180°)	32.00	21.10	49.52	27.43	59.39	30.88
	Counter-aligned (max.180°)	67.25	35.01	103.29	32.95	107.05	28.25

Freehand map drawing task. An ANOVA was run for the freehand map drawing task accuracy (SQRT-CO), inputting Group (young vs. young-old vs. old-old) as the independent variable. Groups significantly differed in map drawing accuracy, $F(2,119) = 23.19$, $\eta^2_p = .28$, $p < .001$. Post-hoc comparisons showed that young adults had an higher SQRT-CO score than the two groups of older adults ($p_s < .001$), who did not differ from one another ($p = .13$).

Sketch map task. An ANOVA was run for the SQRT-CO in the sketch map task, inputting Group (young vs. young-old vs. old-old) as the independent variable. The groups differed significantly in the SQRT-CO, $F(2,119) = 19.81$, $\eta^2_p = .25$, $p < .001$. Post-hoc comparisons showed that young-old adults did not differ from young adults ($p_s = 1.00$), while the old-old had a lower SQRT-CO score than the other two groups ($p_s < .001$).

Pointing task. A 3 (Group: young vs. young-old vs. old-old) × 2 (Type of pointing: aligned vs. counter-aligned) ANOVA was run on the mean degrees of error. The main effect of Group was significant, $F(2,117) = 23.99$, $\eta_p^2 = .29$, $p < .001$: the young ($M = 49.63$, $SD = 28.06$) had fewer degrees of error than the young-old ($M = 76.41$, $SD = 30.19$) and old-old ($M = 83.22$, $SD = 29.57$; $p_s < .001$), who did not differ from one another ($p = .56$). The main effect of Type of pointing was also significant, $F(1,117) = 177.32$, $\eta^2_p =$

.60, $p < .001$, the mean degrees of error being fewer in aligned than in counter-aligned pointing (see Table 2.2. for descriptive statistics). The Group × Type of pointing interaction were not significant ($p = .08$).

2.3.2. Relationship between spatial recall tasks and visuo-spatial factors

2.3.2.1. Preliminary analyses: tasks testing VSWM and visuo-spatial abilities

Visuo-spatial tasks. Three univariate ANOVAs were run on the JPT, sMRT and sOPT scores, inputting Group (young vs. young-old vs. old-old) as the independent variable. See Table 2.3 for the corresponding descriptive statistics. The main effect of Group was significant for all the ANOVAs: JPT, $F(2, 119) = 58.60$, $\eta^2_p = .50$, $p < .001$; sMRT, $F(2, 119) = 27.38$, $\eta^2_p = .32$, $p < .001$; sOPT, $F(2, 119) = 23.11$, $\eta^2_p = .28$, $p < .001$. Post-hoc comparisons showed that young adults performed better than the young-old and old-old in the JPT and sOPT ($p_s < .001$), and the latter two groups did not differ from one another (JPT: $p = .83$; sOPT: $p = 1.00$); in the sMRT the young performed better than all the older adults ($p_s < .001$), and the young-old performed better than the old-old ($p = .02$).

Table 2.3. *Means (M) and standard deviations (SD) for visuo-spatial tasks and learning strategies use.*

		Young adults		Young-old adults		Old-old adults	
		M	*SD*	*M*	*SD*	*M*	*SD*
Visuo-spatial tasks	JPT (max. 29)	22.25	5.66	12.83	4.33	11.65	4.28
	sMRT (max. 10)	3.98	3.01	1.85	1.72	0.60	0.84
	sOPT (max. 180°)	42.17	35.93	89.18	40.00	90.89	32.05
Learning strategy use	Route (max. 10)	4.10	1.75	4.88	2.09	5.13	1.77
	Survey (max. 10)	6.18	1.80	5.90	1.53	6.00	1.26
	Verbal (max. 10)	4.23	1.37	4.43	1.81	4.48	1.52

Note. JPT = Jigsaw Puzzle Test; sMRT = short Mental Rotations Test; sOPT = short Object Perspective Taking Test.

Learning strategy use scale. A 3 (Group: young vs. young-old vs. old-old) × 3 (Type of strategy: route vs. survey vs. verbal) ANOVA was run. See Table 2.3. for descriptive statistics. The main effect of Type of strategy was significant, $F(2,116) = 42.46$, $\eta^2_p = .42$, $p < .001$. Post-hoc comparisons showed that the survey strategy was used more than the route and verbal strategies ($p_s < .001$), which did not differ from one another ($p = .07$). The main effect of Group ($p = .42$) and the Group × Type of strategy interaction ($p = .08$) were not significant.

2.3.2.2. Correlations

We explored the relationships between age, VSWM (JPT), visuo-spatial abilities (sMRT and sOPT), strategy use and spatial recall performance (number of missing landmarks and accuracy for the freehand map drawing and sketch map tasks, pointing errors for the aligned and counter-aligned pointing task; see Table 2.4.).

Summarizing, spatial recall performance correlated with age, VSWM, sMRT and sOPT (although with some differences); the survey strategy only correlated with the freehand map drawing task (see Table 2.4.). The number of missing landmarks strongly correlated with accuracy (in line with Gardony et al., 2016), thus it was disregarded in the following analyses.

Table 2.4. *Correlations between age, visuo-spatial tasks and GMDA parameters.*

	1	2	3	4	5	6	7	8	9	10	11	12
1. Age	-											
2. JPT (VSWM)	-.72	-										
3. sMRT	-.57	.62	-									
4. sOPT	.54	-.68	-.55	-								
5. Route strategy	.21	-.18	-.06	.20	-							
6. Survey strategy	-.08	.16	.21	-.19	.13	-						
7. Verbal strategy	.08	-.09	-.02	.13	.66	.20	-					
8. No. of missing landmarks – Map drawing	.56	-.54	-.49	.48	-.04	-.34	-.05	-				
9. Map drawing accuracy	-.57	.57	.49	-.53	-.02	.29	-.03	-.95	-			
10. No. of missing landmarks – Sketch map	.33	-.16	-.15	.09	-.09	-.08	.01	.56	-.54	-		
11. Sketch map accuracy	-.41	.30	.22	-.24	.04	.14	-.01	-.70	.71	-.95	-	
12. Aligned pointing	.39	-.46	-.33	.26	.04	-.13	.04	.44	-.46	.22	-.33	-
13. Counter-aligned pointing	.49	-.57	-.55	.50	.15	-.11	.06	.47	-.50	.17	-.27	.35

Note. $N = 120$. JPT = Jigsaw Puzzle Test; VSWM = Visuo-spatial working memory; sMRT = short Mental Rotations Test; sOPT = short Object Perspective Taking Test. For $|r| \geq .20$, $p < .05$, and for $|r| \geq .24$, $p < .01$.

2.3.2.3. Regression models

Regression models were run on the following dependent variables: i) freehand map drawing accuracy; ii) sketch map task accuracy; iii) aligned pointing performance; and iv) counter-aligned pointing performance. Predictors were entered in the models as follows: age (Step 1); VSWM (JPT), considered as a basic cognitive ability sustaining spatial learning (e.g., Borella et al., 2015; Step 2); visuo-spatial (rotation and perspective-taking) abilities, considered as higher-level cognitive abilities (Step 3); self-reported route, survey, and verbal strategy use (Step 4). The order was based on theoretical considerations (e.g., Meneghetti, Borella, Muffato, et al., 2014). Thus, after controlling for age (Step 1), the subsequent models (Steps 2, 3 and 4) assessed the contribution of visuo-spatial factors: from basic to higher-level abilities and self-reported strategy use. Predictors were entered one at a time, and were considered as relevant only if they contributed to reduce the model's Akaike's information criterion (AIC). AIC allows comparing the relative quality of models: the better the model, the lower is AIC (Burnham & Anderson, 2002). Thus, the evidence ratio of Akaike weights[2] and *F*-test were used to confirm improvement of the models between steps; moreover, the R^2 was reported to account for the variance explained.

There were no outliers in any of the models (Cook's distance <1). The results are summarized in Table 2.5., which includes for each step the ΔR^2, the evidence ratio (respect to the previous model), Anova (comparing the model with the previous one), standardized β and *p* values.

Freehand map drawing. The predictors explained 46% of the overall variance. Age accounted for a significant part of the variance (33%) and, in subsequent steps, VSWM ability explained another 5%, visuo-spatial (rotation) abilities 4% and survey strategy use 5%. The better model was Step 4 (see Table 2.5).

Sketch map task. The predictors explained a total of 20% of the variance and the only significant predictor was Age, accounting for 17%. The better model was Step 1 (see Table 2.5).

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[2] $Evidence\ ratio = e^{\frac{AIC(model\ B) - AIC(model\ A)}{2}}$

Table 2.5. *Regression models for freehand map drawing, sketch map and pointing tasks.*

	Freehand map drawing				Sketch map				Pointing							
	SQRT-CO				SQRT-CO				Aligned				Counter-aligned			
Predictors	ΔR^2	*Evidence ratio*	*Anova*	β	ΔR^2	*Evidence ratio*	*Anova*	β	ΔR^2	*Evidence ratio*	*Anova*	β	ΔR^2	*Evidence ratio*	*Anova*	β
Null model																
Step 1: Age	**.33*****	**$9 *10^9$**	***p* < .001**	**-.57*****	**.17*****	**$2*10^4$**	***p* < .001**	**-.41*****	**.15*****	**$7*10^3$**	***p* < .001**	**.39*****	**.24*****	**$4*10^6$**	***p* < .001**	**.49*****
Step 2: VSWM (JPT)	**.05****	**38**	***p* = .002**	**.32****	.00	0.37	*p* = .93	.01	**.07****	**44.59**	**.003**	**-.37****	**.10*****	**$1*10^3$**	***p* < .001**	**-.45*****
Step 3: Visuo-spatial abilities	**.03***	**11.39**	***p* = .008**	**.28***	.00	0.37	*p* = .99	.01	.00	0.38	.80	-.03	**.06****	**113**	***p* = .001**	**-.38****
Step 4: Strategies	**.05****	**7.61**	***p* = .023**		.03	0.78	*p* = .16		.01	0.10	.71		.00	0.07	.91	
Route strategy				.16				.22				-.10				.06
Survey strategy				**.19***				.11				-.07				.02
Verbal strategy				-.12				-.15				.08				.05
Total R^2	**.46*****				**.20*****				**.23*****				**.40*****			

Note. *N* = 120; VSWM = Visuo-spatial working memory; JPT = Jigsaw Puzzle Test; Visuo-spatial abilities: composite score of sMRT and sOPT. SQRT-CO = Square Root Canonical Organization. **p*<.05, ***p*<.01, ****p*<.001. Significant values in bold type. Evidence ratio is based on AIC of the models (each step is a model); the “Anova” column shows the comparison between a model (step) and the previous model (step).

Pointing task, aligned. The predictors explained 23% of the overall variance. Age accounted for a significant part of the variance (15%) and, in the subsequent step, VSWM ability (JPT) explained another 7%. The better model was Step 2 (see Table 2.5).

Pointing task, counter-aligned. The predictors explained a total of 40% of the variance. Age accounted for a significant part of the variance (24%) and, in subsequent steps, VSWM ability and visuo-spatial (rotation) abilities accounted for a significant portion of the variance, with 10% and 6% respectively. The better model was Step 3 (see Table 2.5).

2.4. Discussion

Study 1 examined the features of mental spatial representations formed by groups of young, young-old and old-old adults after learning from a map (an allocentrically-based stimulus), and the underlying individual visuo-spatial factors that contributed to their mental representations. The aims of the study focused on: i) map recall accuracy in the three age groups; and ii) the role of individual visuo-spatial factors in participants' mental spatial representations. The results obtained are discussed following these two objectives.

2.4.1. Map recall in young, young-old and old-old adults

Map learning performance changed as a function of the type of recall task used. When the tasks were consistent with the allocentrically-based input modality (as in the case of a graphical representation of the environment), the results differed if the map had to be reproduced on a blank sheet of paper (the freehand map drawing task) or if a set of landmarks had to be placed in a skeletal layout (the sketch map task). Young-old and old-old adults were both less accurate than young adults, and to much the same degree, in the freehand map drawing task. On the other hand, the young-old performed as well as the younger adults when they were given cues (a list of landmarks and the layout of the environment), while the old-old did less well, and failed to profit from the cues. These results show that the old-old are more impaired in an allocentric ability (Gazova et al., 2013; Ruggiero et al., 2016) than the young-old. In the pointing task, both the young-old and the old-old performed less well than the young adults – a pattern of results in line with previous studies showing that older adults struggle with adopting new imaginary positions in an environment (e.g., Muffato et al., 2015).

Overall, the ability to form mental representations of a map seems to deteriorate progressively with aging. Young-old individuals are still able to compensate for this decline in situations where cues are available, however. These age-related differences as a function of the type of recall task emerged even more clearly from the analysis of visuo-spatial factors.

2.4.2. Map recall and visuo-spatial factors

Performance in visuo-spatial tasks showed an age-related decline (Techentin et al., 2014), whereas no age-related differences emerged concerning self-reported strategy use. This is consistent with studies demonstrating that age-related differences may be attenuated or disappear in self-report measures (e.g., Borella et al., 2014). These individual visuo-spatial factors influenced our participants' map learning accuracy, especially in certain types of recall task. The role of individual visuo-spatial factors was more limited (or nonexistent) in tasks that are less spatial resource consuming, such as aligned pointing and sketch map tasks, while their role was important in recall tasks particularly liable to age-related differences (freehand map drawing and counter-aligned pointing).

As concerns freehand map drawing, accuracy was predicted not only by age, but also by VSWM, visuo-spatial (rotation) abilities and the self-reported use of a survey strategy. Strategy use is of interest when considering older people's spatial (map) learning abilities. Studies on young adults have demonstrated a better spatial recall in people who spontaneously report having used visuo-spatial strategies, such as forming a mental map of the environment (Meneghetti, Ronconi, et al., 2014). Instructing older people to use spatial strategies can improve their spatial performance too (Thomas et al., 2012). Future studies should consider this issue more carefully.

In the pointing task, both aligned and counter-aligned pointing performance was accounted for by age and also by individual visuo-spatial factors, and particularly VSWM in the aligned condition, and both VSWM and visuo-spatial (rotation) abilities in the counter-aligned condition. It is more difficult to imagine adopting views counter-aligned with the one used in the learning phase, and this demands stronger visuo-spatial abilities, as demonstrated by the double variance explained by individual visuo-spatial factors in counter-aligned pointing with respect to aligned pointing.

On the whole, taking individual visuo-spatial factors into account enabled us to elucidate how these competences still support spatial learning accuracy in aging (Meneghetti, Borella, Muffato, et al., 2014) in the case of learning from maps, also as a function of the type of task considered.

3. Study 2.

Route learning from navigation in young and older adults: the role of the type of task and visuo-spatial factors

3.1. Rationale and aim of the study

In Study 2[3], we investigated route learning from real navigation in an environment in an effort to clarify the features of spatial mental representations in relation to age, different types of task, and individual visuo-spatial factors.

The first theoretical premise is that there is an age-related decline in the ability to learn a route from navigation (e.g., Barrash, 1994; Wilkniss et al., 1997), but older adults may perform as well as young adults when some types of recall task are used (Cushman et al., 2008). It is therefore worth trying to pinpoint which types of task support route learning in older adults and might be able to at least partly reduce the known age-related differences.

The second theoretical premise is that some studies have produced encouraging evidence of a relationship between environment recall and visuo-spatial abilities in the case of learning routes from verbal spatial descriptions (Meneghetti, Borella, Muffato, et al., 2014), or from maps (Study 1 in the present project), and there is some evidence of this relationship for route learning from navigation too (Kirasic, 2000). The simultaneous influence of people's different individual visuo-spatial factors (such as VSWM and rotation abilities), age and performance in different types of task has yet to be thoroughly investigated, however.

The present study consequently aimed to compare route learning in young and older adults, and to ascertain how their accuracy relates to their visuo-spatial abilities.

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[3] Study 2 have been described in Muffato, Meneghetti, and De Beni (2016).

Our research hypotheses were as follows:

i) *Age-related differences in spatial learning*. We expected to find age-related differences in a route repetition task (Barrash, 1994; Wilkniss et al., 1997), a pointing task (as suggested using different learning inputs, Borella et al., 2015), and a map drawing task (Head & Isom, 2010); but age-related differences may vary depending on the specific type of demand imposed by a given task (e.g., Cushman et al., 2008). We therefore investigated whether age-related differences emerged for both aligned and counter-aligned pointing (e.g., De Beni et al., 2006) and for recalling and locating landmarks (e.g., Meneghetti, Borella, Gyselinck, et al., 2012).

ii) *Spatial learning and individual visuo-spatial factors.* Although VSWM and visuo-spatial abilities decline over time, we would expect these abilities to continue to sustain route learning from navigation to some degree in aging too (Kirasic, 2000), here again possibly subject to the type of task administered.

3.2. Method

3.2.1. Participants

The study involved 38 young adults (24-35 years old; 20 females) and 37 older adults (64-75 years old; 22 females) for a total of 75 people. There was no significant difference in the number of males and female in each group ($\chi^2_{(1)}$= 0.36, *p* = .55). All participants were volunteers recruited by word of mouth. Our inclusion criteria were: Italian mother tongue, and for the older group living independently. None of the participants had worked in jobs requiring navigational skills (e.g., Kozhevnikov et al., 2005). The following exclusion criteria were adopted: a history of psychiatric or neurological diseases, use of benzodiazepines in previous months, symptomatic cardiovascular conditions, breathing problems, diseases capable of causing cognitive impairments, visual, auditory and/or motor impairments (Crook et al., 1986), as established from a semi-structured interview; familiarity with the botanical garden in Padua (Italy); and a score of more than 27 in the MMSE (Folstein et al., 1975) for older participants.

The groups differed in years of formal education ($F(1,74)=14.26$, $\eta^2_p = .16$, $p < .001$), but this difference was representative of the Italian population (ISTAT, 2011). Moreover, all participants had completed their compulsory schooling. The young and older adults also did not differ in terms of their crystallized abilities, $F = 1.00$, $p = .32$, as assessed with the vocabulary test (WAIS, Wechsler, 1981). See Table 3.1. for participants' characteristics.

Table 3.1. *Means (M) and standard deviations (SD) of participants' characteristics.*

	Young adults (*N* = 38)		Young-Old adults (*N* = 37)	
	M	*SD*	*M*	*SD*
Age	26.34	3.14	67.30	3.26
Education	15.92	2.57	13.14	3.73
Vocabulary score	50.21	9.55	48.19	7.82

3.2.2. Materials

3.2.2.1. Session 1

As in Study 1.

3.2.2.2. Session 2

3.2.2.2.1. Learning phase

The route navigated in the learning phase is in a botanical garden in Padua (see Figure 1, panel a). The route is a pedestrian path 550 meters long, with a total of 10 turning points. 15 landmarks (the same of Study 1) became visible along the way (see Figure 2.1). The route starts next to the ticket office, proceeds through the west gate and passes seven landmarks inside the walls. Then it goes out through the south gate, passes the roundabout, shrubbery and annual plants, and ends at the starting point (i.e., the ticket office).

3.2.2.2.2. Recall phase

Route repetition task. This involved re-walking along the previously learned route and, when each of the landmarks became visible along the way, they had to be identified by naming them, and participants had to decide which way to turn (10 turning points).

The experimenter walked behind participants and provided feedback when they made mistakes in identifying the landmarks, or moved in the wrong direction. For scoring purposes, we considered the number of landmarks correctly identified (one point for each landmark; max: 15) and the number of correctly taken directions (one point for each turn; max: 10).

Pointing task. This involved having to imagine standing at a given landmark, facing another, and pointing to a third. For each item, the question was written at the top of a page and the answer was given using a circle depicted below (see Figure 2.3.). After two trial items for familiarization purposes, 12 items were administered: 6 of which involve adopting an orientation aligned with the route learned (e.g., “Imagine standing at the west gate and facing the crossing, then point to the north gate”) and the other 6 an orientation counter-aligned with the direction of the route previously walked (e.g., “Imagine standing at the crossing and facing the west gate, then point to the north gate”). To score the pointing task, for the minimum angle between each participant’s response and the correct direction was calculated for each item, then the mean error using circular statistics was considered as the total score (for details see Borella et al., 2015).

Map drawing task. This involves drawing a map on a blank sheet of A4 paper and positioning the landmarks on it so that they are in the right relationship with one another. Scoring was done with the GMDA (Gardony et al., 2016), as in Study 1. The square root of the canonical organization (SQRT-CO) was considered as a global index of drawing accuracy (ranged from 0 to 1): higher scores indicate a more accurate landmark positioning. We considered also the number of missing landmarks, i.e., those not recalled and located on the map.

3.2.3. Procedure

Participants signed an informed consent form and individually attended two sessions, the first at a psychology lab and the second at the botanical garden and in an adjacent room, for a total of two hours on two different days in the same week. During the first session, participants completed the MMSE (for the older participants), the vocabulary test and the visuo-spatial tasks (JPT, sMRT and sOPT, in a balanced order across participants). During the second session, participants met the experimenter outside the botanical garden. Once they had entered the botanical garden, they were to follow the experimenter along a route and learn only the landmarks that the experimenter showed them and the directions (turns) along the way. Before starting, they were told that they would be asked afterwards to solve tasks concerning this information. Then participants and experimenter started walking side by side and, when they came up alongside each landmark, they would stop and the experimenter would point to and name the landmark (i.e., “This is the ticket office”). When they reached the first gate (i.e., the west gate), the experimenter would identify it (i.e., “this is the west gate”) and also point towards the other three gates (i.e., “the east gate is there in front of you, to your left the north gate, and to your right the south gate”). The other landmarks were presented in the order depicted in Figure 2.1., and the route ended at the starting point.

After the learning phase, participants were asked to perform the route repetition task, i.e., to re-walk the route and to identify each landmark encountered. The experimenter (right behind the participant) recorded the accuracy in identifying the landmarks and in the turns people took. When participants made a mistake or missed a landmark, the experimenter provided feedback by identifying the landmark, or showing the right direction to take along the route.

Participants were then accompanied to a quiet room in an adjacent building, from where the botanical garden was not visible. Participants seated facing north, but they were given no information about the cardinal directions. They completed the pointing and the map drawing tasks.

3.3. Results

3.3.1. Learning phase

Participants spent about 8 minutes (481 seconds) following the experimenter along the route. The young group (M = 461 seconds, SD = 33) completed the learning phase significantly faster ($F(1,74) = 15.30$, $\eta^2 = .17$, $p < .001$) than the older adults (M = 503 seconds, SD = 57), but the difference was less than a minute (42 seconds).

3.3.2. Spatial recall tasks in the age groups

Route repetition task. The task lasted about 8 minutes like the learning phase. The young group (M = 444 seconds, SD = 69) completed the task significantly faster ($F(1,74) = 15.54$, $\eta^2 = .18$, $p < .001$) than the older adults (M = 519 seconds, SD = 93).

Two ANOVAs were run, one inputting the number of landmarks correctly identified as dependent variable, and the other the number of correct turns taken, both inputting Group (young vs. young-old) as the independent variable. The group effect emerged only for landmark identification, $F(1,74) = 10.87$, $\eta^2 = .13$, $p = .002$, the young adults being more accurate than the older group, and not in the turns taken ($F < 1$; $p = .96$), where both young and young-old adults were very accurate in choosing which way to turn. See descriptive statistics in Table 3.2.

Pointing task. An ANOVA with Group (young vs. young-old) × Type of pointing (aligned vs. counter-aligned with the route) as the independent variables, and pointing errors as the dependent variable was run. The main effect of Group emerged, $F(1,74) = 10.57$, $\eta^2_p = .13$, $p < .01$: young adults had fewer degrees of error (M = 51.96, SD = 34.76) than young-old adults (M = 73.41, SD = 33.18). The main effect of Type of pointing ($F < 1$, $p = .99$; aligned: M = 62.73, SD = 32.68, counter-aligned: M = 62.64, SD = 35.27) and the Group × Type of pointing interaction ($F < 1$, $p = .34$) were not significant. See Table 3.2 for the corresponding descriptive statistics.

Table 3.2. *Means (M) and standard deviations (SD) for spatial task performance.*

		Young adults		Young-Old adults	
		M	*SD*	*M*	*SD*
Route repetition	Landmark identification (0-15)	11.79	2.36	9.97	2.41
	Turns (0-10)	9.39	1.00	9.41	0.80
Pointing task (0-180° errors)	Aligned with the route	49.93	32.56	75.52	32.79
	Counter-aligned with the route	53.98	36.96	71.29	33.57
Map drawing	SQRT-CO (0-1)	.88	.10	.82	.11
	No. of missing landmarks (0-15)	0.76	1.32	1.19	1.24

Map drawing task. Two ANOVAs were run, inputting Group (young vs. old) as the independent variable and the accuracy (SQRT-CO) and the number of missing landmarks as dependent variables. The results showed the group effect for accuracy, $F(1,74) = 5.79$, $\eta^2 = .07$, $p = .02$, but not for missing landmarks, $F(1,74) = 3.40$, $p = .16$. Young adults located landmarks better than young-old adults, but the two age groups missed a similar number of landmarks (about one landmark). See Table 3.2 for the corresponding descriptive statistics.

3.3.3. Relationship between spatial recall tasks and visuo-spatial factors

3.3.3.1. Preliminary analyses: tasks testing VSWM and visuo-spatial abilities

ANOVAs were run for the JPT, sMRT and sOPT, inputting Group (young vs. young-old) as the independent variable. See Table 3.3. for the corresponding descriptive statistics. In all three ANOVAs, the groups differed significantly (JPT: $F(1,74) = 24.40$, $\eta^2 = .25$, $p < .001$; sMRT: $F(1,74) = 23.40$, $\eta^2 = .24$, $p < .001$; sOPT: $F(1,74) = 5.25$, $\eta^2 = .07$, $p = .03$), the older adults performing less well than the young adults in all three visuo-spatial tasks.

Table 3.3. *Means (M) and standard deviations (SD) for visuo-spatial tasks.*

	Young adults		Young-Old adults	
	M	*SD*	*M*	*SD*
VSWM (max. 29)	25.50	4.39	19.76	5.62
sMRT (max. 10)	4.29	3.14	1.60	1.30
sOPT (max. 180 degrees)	32.89	32.72	54.17	46.66

Note. VSWM = visuo-spatial working memory (Jigsaw Puzzle Test, JPT); sMRT = short Mental Rotations Test; sOPT = short Object Perspective Test.

3.3.3.2. Correlations

Correlations were run between age, visuo-spatial abilities and spatial recall tasks, i.e., route repetition accuracy (number of landmarks correctly identified), the total score in the pointing task (given that no difference was found between aligned and counter-aligned items), and the accuracy for the map drawing task (the number of missing landmarks correlated closely with the SQRT-CO, $r = -.86$, $p < .01$, as also postulated by Gardony et al., 2016). See Table 3.4. for the corresponding *r*.

Table 3.4. *Correlations between age, visuo-spatial factors and spatial recall tasks.*

	1	2	3	4	5	6
1. Age	-					
2. JPT (VSWM)	-.51	-				
3. sMRT	-.49	.48	-			
4. sOPT	.28	-.34	-.40	-		
5. Route repetition accuracy	-.32	.21	.39	-.35	-	
6. Pointing task errors (total)	.35	-.42	-.58	.47	-.26	-
7. Map drawing accuracy	-.26	.28	.36	-.38	.44	-.35

Note. $N = 75$. JPT = Jigsaw Puzzle Test; VSWM = Visuo-spatial working memory; sMRT = short Mental Rotations Test; sOPT = short Object Perspective Taking Test. For $|r| \geq .26$, $p < .05$; for $|r| \geq .32$, $p < .01$; for $|r| \geq .40$, $p < .001$.

Age correlated with VSWM (JPT), visuo-spatial abilities (sMRT and sOPT) and spatial recall tasks (pointing errors, route repetition, and map drawing accuracy). Accuracy in the route repetition task also correlated moderately with visuo-spatial abilities, but not with VSWM. Pointing errors and map drawing accuracy showed a medium to large correlation with both VSWM and visuo-spatial abilities (sMRT and sOPT).

3.3.3.3. Regression models

To thoroughly analyze the relationships between the variables, models were run considering the following dependent variables: i) route repetition accuracy; ii) pointing errors; and iii) map drawing accuracy. Based on theoretical assumptions and previous studies (Meneghetti, Borella, Muffato, et al., 2014; see also Study 1), the predictors were entered as follows: age group (Step 1); VSWM (JPT; Step 2) as a basic cognitive ability sustaining spatial learning; and visuo-spatial abilities (sMRT, sOPT; Step 3) as higher-level abilities.

Predictors were entered one at a time, and were considered as relevant only if they contributed to reduce the model's AIC (Burnham & Anderson, 2002). Thus, the evidence ratio^2 and *F*-test were used to confirm improvement of the models between steps;

moreover, the R^2 was reported to account for the variance explained. All the models were checked for outliers (Cook's distance <1). The results are summarized in Table 3.5., which includes for each step the ΔR^2, the evidence ratio (respect to the previous model), Anova (comparing the model with the previous one), standardized β and *p* values.

Route repetition task. The predictors explained 23% of the total variance. Age group accounted for a significant part (13%) of the variance and, in the subsequent steps, only visuo-spatial abilities explained another 10%. Thus, adding VSWM did not improve the model, while the model improved after adding visuo-spatial abilities.

Pointing task. The predictors explained 42% of the overall variance. Age group accounted for a significant part (14%) of the variance, VSWM for another significant part (7%), and visuo-spatial (rotation) abilities for a further significant part (21%). The better model was the model 3: both adding VSWM and visuo-spatial abilities improved the model.

Map drawing task. The predictors explained 20% of the total variance. Age group accounted for a significant part (7%) of the variance, and only visuo-spatial (rotation) abilities accounted for a significant part in the subsequent steps (10%). Therefore, adding VSWM did not improve the model, while the model improved after adding visuo-spatial abilities.

Table 3.5. *Regression models for route repetition accuracy (in identifying landmarks), pointing errors and map drawing accuracy.*

	Route repetition accuracy				Pointing errors				Map drawing accuracy			
Predictors	ΔR^2	*Evidence ratio*	*Anova*	β	ΔR^2	*Evidence ratio*	*Anova*	β	ΔR^2	*Evidence ratio*	*Anova*	β
Null model												
Step 1: Age group[a]	**.13****	**67.15**	**$p < .001$**	**-.36****	**.14*****	**106.38**	**$p < .001$**	**.37*****	**.07***	**6.42**	**$p = .01$**	**-.27***
Step 2: VSWM (JPT)	.00	0.38	$p = .78$	.03	**.07****	**9.62**	**$p = .005$**	**-.31***	.03	1.17	$p = .12$	.19
Step 3: Visuo-spatial abilities	**.10****	**13.67**	**$p = .01$**		**.21*****	**$1*10^4$**	**$p < .001$**		**.10****	**12.96**	**$p = .01$**	
sMRT				.23				**-.39*****				.19
sOPT				-.22				**.25***				**-.26***
Total R^2	**.23****				**.42*****				**.20****			

Note. $N = 75$; VSWM = Visuo-spatial working memory; JPT = Jigsaw Puzzle Test; sMRT = short Mental Rotations Test; sOPT = short Object Perspective Taking Test. [a]Age group: 0 = young, 1 = young-old;. *$p<.05$, **$p<.01$, ***$p<.001$. Significant values in bold type. Evidence ratio is based on AIC of the models (each step is a model); the "Anova" column shows the comparison between a model (step) and the previous model (step).

3.4. Discussion

The present study explored the role of age-related differences in route learning from real navigation in an environment, assessing the performance with a series of recall tasks, in relation also to the role of individual visuo-spatial factors. Young and young-old adults were assessed in their VSWM and visuo-spatial abilities, and then learned a route by walking in an unfamiliar botanical garden. Their spatial recall was tested using route repetition, pointing and map drawing tasks. The role of age and the role of VSWM and visuo-spatial abilities are discussed in the following sections.

3.4.1. Route recall in young and young-old

Age-related differences were found in all the various types of task, but not in all the demands of a given task. Older adults were less accurate than young in landmark identification during route repetition (e.g., Barrash, 1994; Taillade et al., 2016; Wiener et al., 2013), in locating accurately the landmarks when they drew a map (Cushman et al., 2008; Head & Isom, 2010; Wilkniss et al., 1997), and in solving the pointing task (as demonstrated only using different sources of learning, such as spatial descriptions, Meneghetti, Borella, Muffato, et al., 2014). Age-related decline did not affect all types of task in the same way, however.

In the route repetition task, older adults performed just as well as young adults in turning points (94% accuracy). One explanation for this could be the fact that the task was completed directly in the setting where they had learned the route. Older adults may compensate somehow by relying on environmental stimuli, i.e., by responding to demands in the same context as the one in which they were learned. In the pointing task, there were no differences due to age between aligned and counter-aligned pointing, i.e., older adults were equally capable of imagining adopting a position actually experienced in the route during the learning phase (0°) or a new, counter-aligned position (180°). This suggest that their representation was not dependent from the perspective learnt (Shelton & McNamara, 2001), and an explanation could be that participants started to learn the route in one view and, walking in a circle, they finished it in the opposite view, and this may have made it easier for them to imagine adopting both aligned and counter-aligned views. In the map drawing task, older adults recalled the landmarks just as well as the young group to draw in the map (on average, all participants missed only one landmark).

Overall, our findings confirm that age-related differences occur in route learning from navigation, but older adults encounter difficulties with some demands, while they can cope with others just as well as younger people. These differences can be better qualified by analyzing the involvement of individual visuo-spatial factors, as discussed in the next section.

3.4.2. Route recall and visuo-spatial factors

Despite their decline (in line with Techentin et al., 2014), visuo-spatial skills still play a part in supporting older people's mental spatial representations. This was ascertained using several regression models, inputting age group, VSWM and visuo-spatial abilities as predictors. The results showed that age group predicted performance in all three tasks considered (route repetition, pointing, and map drawing) when input in the first step, thus confirming the effect of age. After controlling for age, however, a better performance in route repetition and map drawing tasks demanded the support of visuo-spatial abilities to some degree. In the pointing task, the influence of visuo-spatial abilities was even stronger, and VSWM influenced performance too in this case. Thus, after controlling for the effect of age, a better VSWM (a basic cognitive resource) predicted fewer pointing errors, and visuo-spatial abilities (sMRT and sOPT) predicted pointing performance, whatever the participant's age or VSWM. The variance explained by these individual variables was twice as high in the pointing task as in the route repetition and map drawing tasks, meaning that these individual visuo-spatial factors were more important in a task that involved actively manipulating spatial information stored in a mental representation, and inferring directions, and less important in tasks preserving the same (egocentric) approach as in the learning phase (the route repetition task) (Wiener et al., 2012), and more static tasks that involve graphically reproducing the environment (the map drawing task).

Overall, the present findings support the idea that spatial recall, in adults young (Hegarty et al., 2006) and old, is supported by individual visuo-spatial factors, such as visuo-spatial abilities (Moffat et al., 2001), but their role changes depending on the type of task administered. The age-related decline in the ability to manage spatial information after learning an environment by navigation can be contained by individual visuo-spatial factors.

4. Study 3.
Map and video learning across the adult lifespan: the role of the type of task and visuo-spatial factors

4.1. Rationale and aims of the study

After separately studying map learning (in Study 1) and route learning from navigation (in Study 2), the two learning inputs were investigated together in Study 3 to see how age and personal visuo-spatial factors influence an individual's mental spatial representations, as assessed with different types of spatial recall task.

The first theoretical premise is that little is known as yet about the role of age when these two inputs are compared directly. Yamamoto and De Girolamo (2012) suggested that map learning is more effective than learning from navigation in aging, but they only used a sketch map task to test participants' recall (i.e., a recall task with the same format as the map learning phase). In Study 3 we therefore used different spatial recall tasks to analyze the mental spatial representations derived from learning a route from a map and from watching a video: one resembling the format of the map learning phase (i.e., a sketch map drawing task), one resembling the format of video learning (i.e., choosing correct directions in a route repetition task), and one that involved making inferences based on spatial knowledge (i.e., a pointing task). We also decided to consider the role of age on a continuum over the adult lifespan (from young adulthood to very old age). This approach has rarely been used in spatial cognition studies (Meneghetti, Borella, Muffato, et al., 2014), but can prove useful for elucidating performance trajectories, in combination with the use of different types of input and different spatial recall tasks.

The second theoretical premise is that individual visuo-spatial factors may be important in spatial learning (e.g., Mitolo et al., 2015), so in Study 3 we also considered the role of VSWM (as measured with the JPT; De Beni et al., 2008), rotation ability (as measured with the sMRT; De Beni et al., 2014), and perspective-taking ability (as measured with the sOPT; De Beni et al., 2014), in combination with the role of age, type of input and type of recall task.

Taking these aspects together, Study 3 aimed to examine age-related differences over the adult lifespan by comparing map and video learning performance in relation to individual visuo-spatial factors. Participants were first asked to perform a series of visuo-spatial tasks. Then they studied a map or a video (presented in a balanced order), and completed a series of recall tasks, i.e., a pointing task, a sketch map drawing task and a route repetition task.

Our research hypotheses were as follows:

i) *Age-related differences in spatial learning*. We expected to find general age-related differences in spatial learning, be it from a map or a video, gradually worsening from youth to old age (Klencklen et al., 2012; Moffat, 2009). We also predicted that performance would depend on the recall tasks used to test spatial learning. In particular, we expected participants to do better in recall tasks in a format similar to that of the learning phase (e.g., graphically reproducing an environment after learning from a map) than when a change of format was involved (e.g., graphically reproducing an environment learned from a video) (Devlin & Wilson, 2010; Yamamoto & DeGirolamo, 2012). We also explored the role of age in combination with different types of learning input, for each spatial recall task.

ii) *Spatial learning and individual visuo-spatial factors.* We examined how individual visuo-spatial factors influenced performance in each task, comparing the two learning modes (map and video). In the pointing task, which involves inference after learning from either type of input, the role of individual visuo-spatial factors was expected to be relevant in mediating between age and performance (Borella et al., 2015; Kirasic, 2000; Meneghetti, Borella, Pastore, et al., 2014). The role of these visuo-spatial factors was explored in tasks using formats similar to and dissimilar from that of the learning phase.

4.2. *Method*

4.2.1. Participants

The study involved 431 people from 25 to 84 years of age, divided into six age groups: 75 participants were 25-34 years old (38 females); 75 were 35-44 years old (38 females); 73 were 45-54 years old (35 females); 75 were 55-64 years old (37 females); 72 were 65-74 years old (38 females); and 61 were 75-84 years old (34 females).

There was no statistically significant difference in the number of males and females in each group ($\chi^2_{(5)}$= 1.00, p = .96). All participants were volunteers recruited by word of mouth in various cities all over Italy. Our inclusion criteria were: Italian mother tongue, and living independently. None of the participants had worked in jobs requiring navigational skills (e.g., drivers; Kozhevnikov et al., 2005). The following exclusion criteria were adopted: individuals with a history of any disease capable of causing cognitive, visual, auditory and/or motor impairments (e.g., psychiatric or neurological diseases; see Crook et al., 1986), as established from a semi-structured interview; familiarity with the environments used in the study (the botanical garden and a park in Padova, Italy); and, for adults aged from 55 to 84 years, a score of less than 26 in the Montreal Cognitive Assessment (MoCA; Conti, Bonazzi, Laiacona, Masina, & Coralli, 2015; Nasreddine et al., 2005).

The age groups differed in terms of participants' years of formal education, $F(5,425)$=18.99, η^2_p= .18, p < .001, the youngest groups (from 25 to 44 years old) having had more years of schooling than the older groups (p_s < .01). These differences are typical of the Italian population (see ISTAT, 2011), and all participants had completed their compulsory schooling (8 years). In terms of their crystallized abilities, participants were assessed with the vocabulary test (WAIS vocabulary subtest, Wechsler, 1981), and a comparison between groups revealed no statistically significant difference in the scores (p_s from .12 to 1.00). See Table 4.1 for participants' details.

Table 4.1. *Means (M) and standard deviations (SD) of participants' characteristics.*

	25-34 years (*N* = 75)		35-44 years (*N* = 75)		45-54 years (*N* = 73)		55-64 years (*N* = 75)		65-74 years (*N* = 72)		75-84 years (*N* = 61)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	27.85	2.67	38.16	2.97	50.26	2.96	58.85	2.58	68.19	2.98	77.98	2.99
Education	14.72	2.81	14.79	2.94	12.32	2.92	12.76	2.96	11.90	3.35	10.84	3.21
Vocabulary score	47.83	8.29	48.93	9.54	45.01	9.61	48.25	8.75	45.54	9.20	44.25	10.14

4.2.2. Materials

4.2.2.1. Session 1

As in Studies 1 and 2.

4.2.2.2. Session 2

4.2.2.2.1. Learning phase

Two outdoor environments were used: the botanical garden (used in the previous studies) and the "Europe" park, both situated in Padova (Italy). Each environment included 15 landmarks (see Appendix A): 4 named using the cardinal points (the north, south, east and west gates at the botanical garden; the north, south, east and west entrances to the park); 1 approximatively in the center of the environment (the crossroads in the botanical garden; the glasshouse in the park); and 10 natural and artificial landmarks (the annual plants, the hillside plants, the magnolia, the medicinal plants, the palm, the pond, the rare plants, the roundabout, the shrubbery, the ticket office in 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 vegetation, the wall, and the wild herbs in the park). In both environment, a route about 550 meters long covers all the landmarks. The route in both environments starts from the west and initially heads south in the botanical garden, and north in the park. A previous pilot study ($N = 40$ participants) demonstrated that performance in a sketch map drawing task ($r = .87$, $p < .001$), and a pointing task ($r = .76$, $p < .001$) correlated closely for the two environments.

Map learning. Maps of the two outdoor environments were prepared and shown on a 15” PC screen using a PowerPoint presentation that lasted six minutes (360 seconds). First, the map showing the whole area of the environment was displayed for 105 seconds, with a fixed red dotted line marking the whole route, and the names of the landmarks written in their corresponding locations. Then a red arrow appeared to indicate the point where the route started. Then a picture of each landmark appeared (for 5 seconds), before the picture was reduced in size and positioned next to the written name of the landmark (taking another 5 seconds; for a total of 150 seconds for all 15 landmarks). This presentation modality has been shown to focus participants’ attention on the path, making the presentation of the landmarks more dynamic than in normal map learning (Yamamoto & DeGirolamo, 2012). The map completed with all the small pictures then remained on the screen for 105 seconds. The maps and examples of the pictures of the landmarks are shown in Figure 4.1.

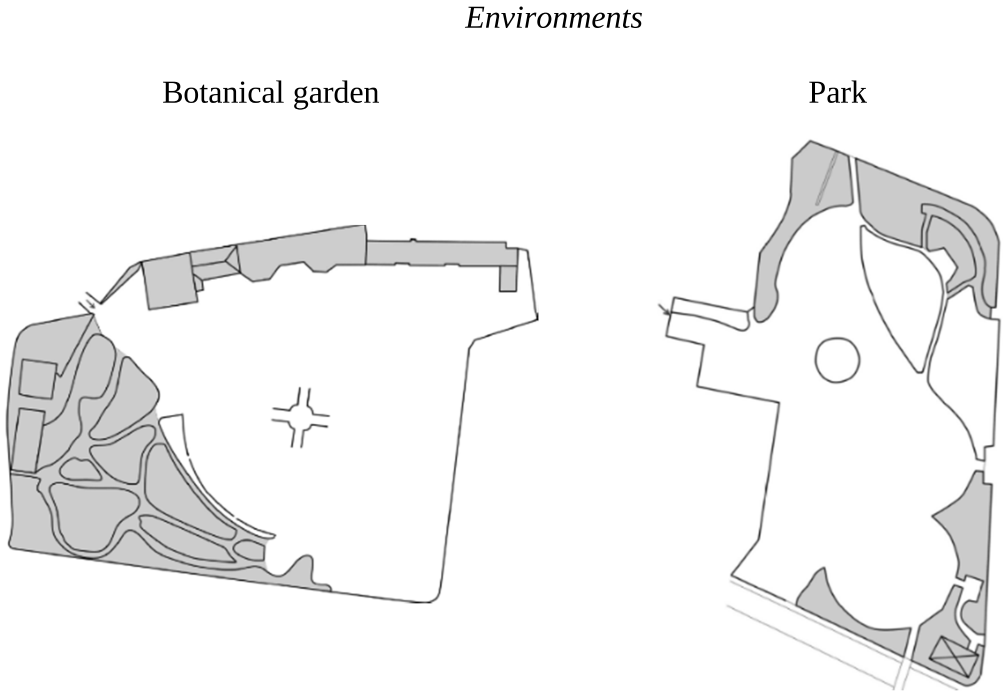
Figure 4.1. *Screenshots of the map and video used for route learning.*

Video learning. Videos showing the environments were recorded, each lasting 6 minutes (as for the map learning procedure), in which the route was followed from a ground-level perspective. When landmarks were encountered along the route, pictures of them (the same as those shown on the map) appeared on the screen with a written label (showing their name and sequential number) for 5 seconds, with a yellow dot indicating their location (see Figure 4.1.).

Recall phase

Sketch map drawing task. This involved writing or drawing the landmarks recalled on a sketch map, positioning them in the right relationship with one another. The sketch map was printed on a sheet of A4 paper and showed salient details of the layout of the environment (such as borders) and an arrow indicating the starting point (see Figure 4.2). The Gardony Map Drawing Analyzer (GMDA, Gardony et al., 2016) was used for scoring purposes. As in the previous studies, the SQRT-CO (square root of the canonical organization) was considered as a global index of drawing accuracy (ranging from 0 to 1; for details see Gardony et al., 2016; Meneghetti et al., 2016), and the number of missing landmarks (those not recalled and located on the map) was considered as a complementary measure.

Figure 4.2. *Sketch map drawing task (botanical garden and park).*



Route repetition task. This involved watching a video of the previously learned route and, when the video stopped, having to decide which way to turn (8 points to choose; see an example in Figure 4.3.). Landmarks became visible along the way but their names were not shown. For each choice, the experimenter provided feedback if a participant chose to go the wrong way. Then the video moved on to the next turning point. For scoring purposes, we considered the number of correctly taken directions (one point for each turn; max 8).

Figure 4.3. *Example of route repetition task (turning points).*

Environments

Botanical garden

Park

Pointing task. This involved having to imagine standing at a given landmark, facing another, and pointing to a third. For each item, the question was written at the top of a page and the answer was given using a circle depicted below (see Figure 2.3.). After two trial items for familiarization purposes, 16 items were administered (e.g., “Imagine standing at the east gate and facing the shrubbery, then point to the north gate”), in random order. To score the pointing task, for the minimum angle between each participant’s response and the correct direction was calculated for each item, then the mean error using circular statistics was considered as the total score (for details see Borella et al., 2015).

4.2.3. Procedure

Participants signed an informed consent form and individually attended two sessions lasting 45 minutes each. In the first session, participants completed the MoCA (for participants aged 55 and over), the vocabulary test and the visuo-spatial tasks (JPT, sMRT and sOPT, in a balanced order across participants). During the second session, they learned the route through one of the environments from a map or video (learning condition), then performed the pointing, route repetition and sketch map drawing tasks, presented in a balanced order across participants. Then they learned the route through the other environment presented in the format not used before (video or map), and again completed the three spatial tasks in a balanced order. There were therefore four possible combinations of the learning condition: 1) Botanical garden map – Europe park video ($N = 109$ participants); 2) Europe park map – Botanical garden video ($N = 104$ participants); 3) Botanical garden video – Europe park map ($N = 110$ participants); 4) Europe park video – Botanical garden map ($N = 108$ participants).

4.3. Results

4.3.1. Spatial recall tasks in the age groups

Three ANOVAs were run for spatial task performance (pointing errors, map drawing and route repetition accuracy), inputting Group (25-34 vs. 35-44 vs. 45-54 vs. 55-64 vs. 65-74 vs. 75-84) and Learning input (map vs. video) as factors.

First gender, years of education and learning combinations were input as covariates, but these variables did not significantly influence the main effects of Group and Learning input, or their interactions (pointing task: gender × learning input, $p = .25$; years of education × learning input, $p = .09$; learning combination × learning input, $p = .53$; map drawing task: gender × learning input, $p = .49$; years of education × learning input, $p = .33$; learning combination × learning input, $p = .08$; route repetition task: gender × learning input, $p = .48$; years of education × learning input, $p = .13$; learning combination × learning input, $p = .20$). These variables were consequently not included in the final analyses.

In the following sections, when post hoc analyses are described, they were run using Bonferroni correction ($p_s < .01$ are considered). See Table 4.2. for descriptive statistics of spatial tasks performance.

Pointing task. A main effect of group was found, $F(5,425) = 7.32$, $\eta^2 = .08$, $p < .001$. Post hoc analysis showed that the group of 75- to 84-year-olds ($M = 86.66$, $SD = 16.85$) had greater degrees of error than the 25- to 34-year-olds (*p* <.001; *M* = 70.97, *SD* = 22.02) or the 35- to 44-year-olds (*p* <.001; *M* = 72.37, *SD* = 23.83), with no difference between the latter two groups (*p* = 1.00). The other groups did not differ from one another (p_s from .04 to 1.00; 45-54 years: *M* = 77.88, *SD* = 22.42; 55-64 years: *M* = 79.41, *SD* = 19.55; 65-74 years: *M* = 78.38, *SD* = 19.09). A main effect of Learning input was also found, *F*(1,425) = 49.00, η^2_p = .10, *p* < .001: there were fewer degrees of error in the pointing task after learning from the map (*M* = 73.49, *SD* = 22.10) than from the video (*M* = 81.74, *SD* = 19.16). The Group × Learning input interaction was significant, *F*(5,425) = 6.84, η^2_p = .08, *p* < .001. Post hoc analysis indicated that only the participants aged 55-64 and 75-84 had the same degrees of error after learning from the map and from the video (55-64: *p* = .20; 75-84: *p* = .15), while the other age groups were more accurate after learning from the map (p_s < .01). Group comparisons in each learning input showed that, after map learning, the groups aged 25-34 and 35-44 scored lower for pointing errors than those aged 55-64 and 75-84 (p_s < .01), the latter two achieving the same performance (*p* = .06). The groups aged 45-54 and 65-74 performed better (fewer degrees of error) than the 75- to 84-year-olds (p_s < .01). The groups aged 25-34, 35-44, 45-54, and 65-74 had the same performance (.12 < p_s < 1.00). After learning from the video, on the other hand, the differences between the groups did not reach statistical significance (.84 < p_s < 1.00). See Table 4.2. for descriptive statistics and Figure 4.4. for a graphical representation of the group effect by learning input.

Sketch map drawing task. A main effect of group was found, *F*(5,425) = 26.64, η^2_p = .24, *p* < .001. Post hoc analysis showed that the group aged 75-84 (*M* = .43, *SD* = .18) was less accurate than the other groups (p_s < .01; 25-34 years: *M* = .67, *SD* = .18; 35-44 years: *M* = .68, *SD* = .15; 45-54 years: *M* = .62, *SD* = .17; 55-64 years: *M* = .56, *SD* = .17; 65-74 years: *M* = .53, *SD* = .19). The group of 25- to 34-year-olds did not differ in terms of accuracy from the groups aged 35-44 (*p* = 1.00) or 45-54 (*p* = .46). The groups aged 25-34 and 35-44 were more accurate (p_s < .001) than the groups aged 55-64, 65-74 and 75-84. The group of 55- to 64-year-olds did not differ in terms of accuracy from the groups aged 45-54 (*p* = .45) or 65-74 (*p* = 1.00). There was a main effect of Learning input, *F*(1,425) = 111.18, η^2_p = .21, *p* < .001, with a better sketch map drawing accuracy after learning from the map (*M* = .63, *SD* = .17) than from the video (*M* = .54, *SD* = .18).

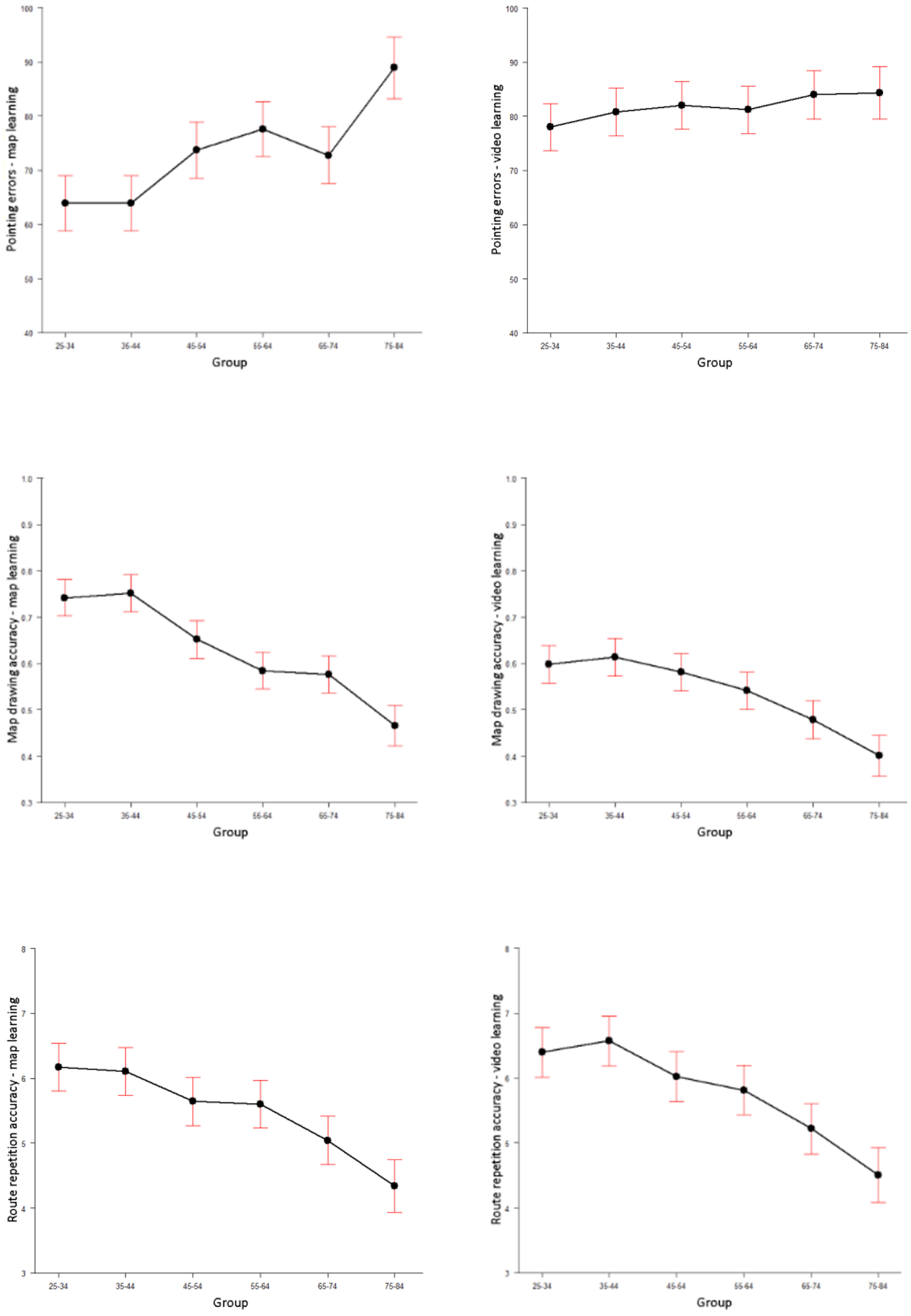
Table 4.2. *Means (M) and standard deviations (SD) for spatial task performance.*

		25-34 years		35-44 years		45-54 years		55-64 years		65-74 years		75-84 years	
	Learning input	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pointing task (0-180° errors)	Map	63.93	24.35	63.91	26.16	73.73	23.88	77.62	20.60	72.80	20.83	88.94	16.76
	Video	78.01	19.69	80.83	21.49	82.02	20.97	81.21	18.50	83.96	17.35	84.39	16.96
Sketch map drawing task (0-1, accuracy)	Map	0.74	0.18	0.75	0.16	0.65	0.17	0.58	0.17	0.58	0.19	0.47	0.18
	Video	0.60	0.20	0.61	0.15	0.58	0.17	0.54	0.17	0.48	0.19	0.40	0.19
Route repetition task (0-8, accuracy)	Map	6.17	1.30	6.11	1.34	5.64	1.76	5.60	1.53	5.04	1.90	4.34	1.81
	Video	6.40	1.59	6.57	1.38	6.03	1.62	5.81	1.64	5.22	1.93	4.51	1.93

The Group × Learning input interaction was significant, $F(5,425) = 3.70$, $\eta^2_p = .04$, $p = .003$. Post hoc analysis revealed that only the group aged 55-64 was equally accurate after learning from both inputs ($p = .04$), while the other groups were more accurate after learning from the map ($p_s < .01$). The comparison between groups in each learning input showed that, after map learning, the groups aged 25-34 and 35-44 did not differ from one another ($p = 1.00$), but did differ from all the other age groups ($p_s < .01$). The groups aged 45-54, 55-64 (which did not differ from one another, p_s from .14 to 1.00), and 65-74 were more accurate than the 75- to 84-year-olds ($p_s < .01$). After learning from the video, the groups aged 25-34, 35-44, and 45-54 were equally accurate ($p_s = 1.00$), and differed from the groups aged 65-74 and 75-84 ($p_s < .01$), with no difference between the latter two groups ($p = .18$). The group aged 55-64 did not differ from either the 25- to 54-year-olds ($.20 < p_s < 1.00$) or the group aged 65-74 ($p = .51$), and was only more accurate than the group aged 75-84 ($p < .001$). See Figure 4.4. for a graphical representation of the group effect for learning input.

Route repetition. There was a main effect of group, $F(5,425) = 19.99$, $\eta^2_p = .19$, $p < .001$. Post hoc analysis showed that the group of 75- to 84-year-olds ($M = 4.43$, $SD = 1.87$) was as accurate as the 65- to 74-year-olds ($p = .04$; $M = 5.13$, $SD = 1.91$), and less accurate than the other groups ($p_s < .001$; 25-34 years: $M = 6.29$, $SD = 1.44$; 35-44 years: $M = 6.34$, $SD = 1.36$; 45-54 years: $M = 5.84$, $SD = 1.69$; 55-64 years: $M = 5.71$, $SD = 1.58$). The group aged 25-34 years did not differ in accuracy from the groups aged 35-44 ($p = 1.00$), 45-54 ($p = .62$), or 55-64 ($p = .13$). The group aged 45-54 performed as well as the groups aged 35-44 ($p = .34$), 55-64 ($p = 1.00$) and 65-74 ($p = .03$), and the 55- to 64-year-olds did as well as the group aged 65-74 ($p = .15$). There was a main effect of Learning input too, $F(1,425) = 8.69$, $\eta^2_p = .02$, $p = .003$, with participants proving more accurate in choosing the route after learning from the video ($M = 5.76$, $SD = 1.68$) than from the map ($M = 5.48$, $SD = 1.60$). The Group × Learning input interaction was not significant $F < 1$, $p = .91$. Figure 4.4. shows a graphical representation of the group effect for learning input.

Figure 4.4. *Graphical representation of group effect for the three spatial recall tasks and both types of input.*



4.3.2. Relationship between spatial recall tasks and visuo-spatial factors

4.3.2.1. Preliminary analyses: tasks testing VSWM and visuo-spatial abilities

ANOVAs were run for the JPT, sMRT and sOPT, inputting Group as the independent variable. In all three ANOVAs, the groups differed significantly.

For VSWM ($F(5,425) = 41.40$, $\eta^2 = .33$, $p < .001$), the groups aged 25-34, 35-44 and 45-54 performed equally well (p_s from .06 to 1.00); the group aged 55-64 performed as well as the groups aged 45-54 ($p = .07$) and 65-74 ($p = 1.00$). The group of 75- to 84-year-olds performed less well than all the other groups ($p_s < .001$).

In the sMRT ($F(5,425) = 480.42$, $\eta^2 = .53$, $p < .001$), the groups aged 25-34 and 35-44 performed equally well ($p = 1.00$). The 25- to 34-year-olds were more accurate than groups aged 45-54, 55-64, 65-74 and 75-84 ($p_s < .001$). The 35- to 44-year-olds performed equally well than the group aged 45-54 ($p = .10$), and higher than the older groups ($p_s < .01$). The groups aged 45-54, 55-64, 65-74 and 75-84 had the same performance (p_s from .03 to 1.00).

In the sOPT ($F(5,425) = 9.35$, $\eta^2 = .10$, $p < .001$), the group aged 25-34 performed better than the group aged 75-84 ($p < .01$) and as well as the others (p_s from .13 to 1.00); the group aged 35-44 performed better than the groups aged 55-64, 65-74 and 75-84 ($p_s < .001$), and as well as the 45- to 54-year-olds ($p = .08$). The group aged 45-54 performed better than the 75- to 84-year-olds ($p = .006$) and as well as the other groups (p_s from .08 to 1.00). The groups aged 55-64, 65-74, and 75-84 did not differ from one another (p_s from .07 to 1.00). Table 4.3. shows the corresponding descriptive statistics.

Table 4.3. *Means (M) and standard deviations (SD) for VSWM and visuo-spatial abilities.*

	25-34 years		35-44 years		45-54 years		55-64 years		65-74 years		75-84 years	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
JPT (VSWM)	22.17	4.38	21.53	4.94	19.89	4.86	17.67	5.17	16.29	4.58	12.16	4.55
sMRT	3.47	2.59	2.91	2.58	2.01	1.89	1.77	1.67	1.47	1.42	0.95	1.12
sOPT	47.44	31.21	37.71	27.04	53.30	37.63	57.52	35.42	62.26	37.38	74.23	33.61

Note. JPT = Jigsaw Puzzle Test (VSWM); sMRT = short Mental Rotations Test; sOPT = short Object Perspective Taking test.

4.3.2.2. Correlations

Correlations were run between age, visuo-spatial factors (JPT, sMRT, and sOPT) and spatial recall tasks (pointing errors, sketch map drawing and route repetition accuracy). Age and visuo-spatial factors correlated with all the spatial recall tasks. See Table 4.4.

Table 4.4. *Correlations between age, visuo-spatial factors and spatial recall tasks.*

	1	2	3	4	5	6	7	8	9
1. Age	-								
2. JPT (VSWM)	-.56	-							
3. sMRT	-.39	.49	-						
4. sOPT	.29	-.50	-.36	-					
5. Pointing task errors – map learning	.31	-.44	-.42	.37	-				
6. Pointing task errors – video learning	.12	-.19	-.23	.25	.34	-			
7. Sketch map accuracy – map learning	-.46	.58	.37	-.37	-.53	-.23	-		
8. Sketch map accuracy – video learning	-.33	.39	.29	-.38	-.30	-.35	.53	-	
9. Route repetition accuracy – map learning	-.32	.39	.22	-.28	-.22	-.11	.36	.32	-
10. Route repetition accuracy – video learning	-.35	.42	.23	-.34	-.20	-.15	.37	.41	.42

Note. $N = 431$. JPT = Jigsaw Puzzle Test; VSWM = Visuo-spatial working memory; sMRT = short Mental Rotations Test; sOPT = short Object Perspective Taking Test. For $|r| \geq .11$, $p < .05$, and for $|r| \geq .21$, $p < .001$.

4.3.2.3. Path analyses

To thoroughly analyze the relationships between age, VSWM, visuo-spatial abilities, and spatial task performance after learning from the map and the video, three path models were run using the “lavaan” package (Rossel, 2012) of the R software (R Core Team, 2015). Pointing task errors in the map and video learning inputs were used as dependent variables in the first model, sketch map drawing accuracy in the map and video learning inputs in the second model, and route repetition accuracy in the map and video learning inputs in the third[4]. This was done in order to compare the same task after learning an environment from a different learning input. Based on theoretical assumptions and previous studies (e.g., Meneghetti, Borella, Muffato, et al., 2014; Studies 1 and 2), age was considered as the initial predictor, and the JPT (VSWM), sMRT and sOPT as variables intervening between age and spatial task performance. VSWM, rotational and perspective-taking abilities were kept separate in order to shed light on their specific role in mediating spatial performance. The sMRT and sOPT both test higher-level cognitive abilities that correlate with one another (they are both visuo-spatial abilities), but they test different aspects, as suggested by Kozhevnikov and Hegarty (2001): sMRT measures rotation ability based on the object, while the sOPT measures perspective-taking ability, which is based on the subject (see also Hegarty & Waller, 2004).

The variance (R^2) accounting for the variables is reported, while the indices of the models' goodness of fit are not because the models were saturated from the start. Covariances between each pair of visuo-spatial tasks (JPT-sMRT, JPT-sOPT, and sMRT-sOPT), and between the spatial recall tasks after using different learning inputs, were input in all the models (and the latter were also inserted in the graphical representations of the models).

Pointing task. In the model considering pointing task errors as the dependent variable (see Figure 4.5.), significant direct relationships were found: i) between age and VSWM (JPT) and visuo-spatial abilities (sMRT and sOPT); and ii) between JPT, sMRT and sOPT and pointing task errors after map learning, and between sMRT and sOPT and pointing errors after video learning (see β and *p* values Figure 4.6). Significant indirect relationships were also found: aging negatively influenced pointing accuracy through the mediation of VSWM (JPT) and visuo-spatial abilities (sMRT and sOPT) after map learning, and through the mediation of visuo-spatial abilities (sMRT and sOPT) after video learning (see corresponding β and *p* values in Table 4.5.). The total variance accounting for pointing errors was 27% after map learning and 9% after video learning,

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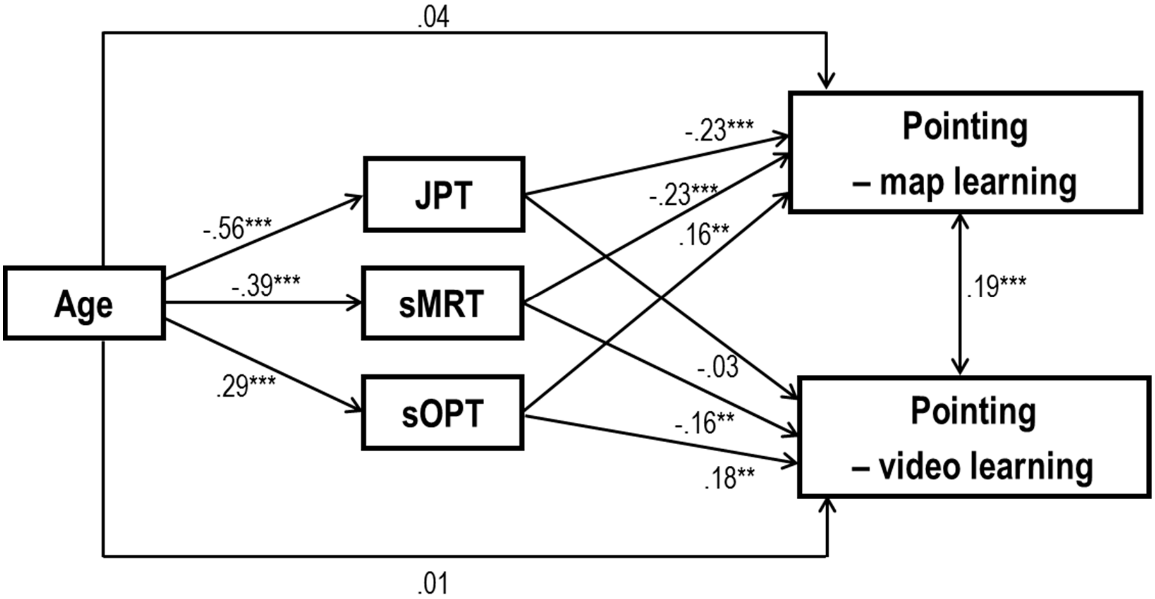
[4] A model was initially run considering all the dependent variables at the same time (pointing after map learning, pointing after video learning, sketch map after map learning, sketch map after video learning, route repetition after map learning, route repetition after video learning). Direct and indirect effects did not change with respect to when the three models were considered separately, so we opted to consider the three models instead of one in order to obtain a clearer picture and show the contribution of age and visuo-spatial factors in each spatial recall task.

and was explained by the significant direct relationship between VSWM and visuo-spatial abilities and pointing performance.

In all three models, the total variance accounting for VSWM (JPT) was 32%, for visuo-spatial rotation ability (sMRT) it was 15%, and for perspective-taking ability (sOPT) it was 8% (explained by the significant relationships with age).

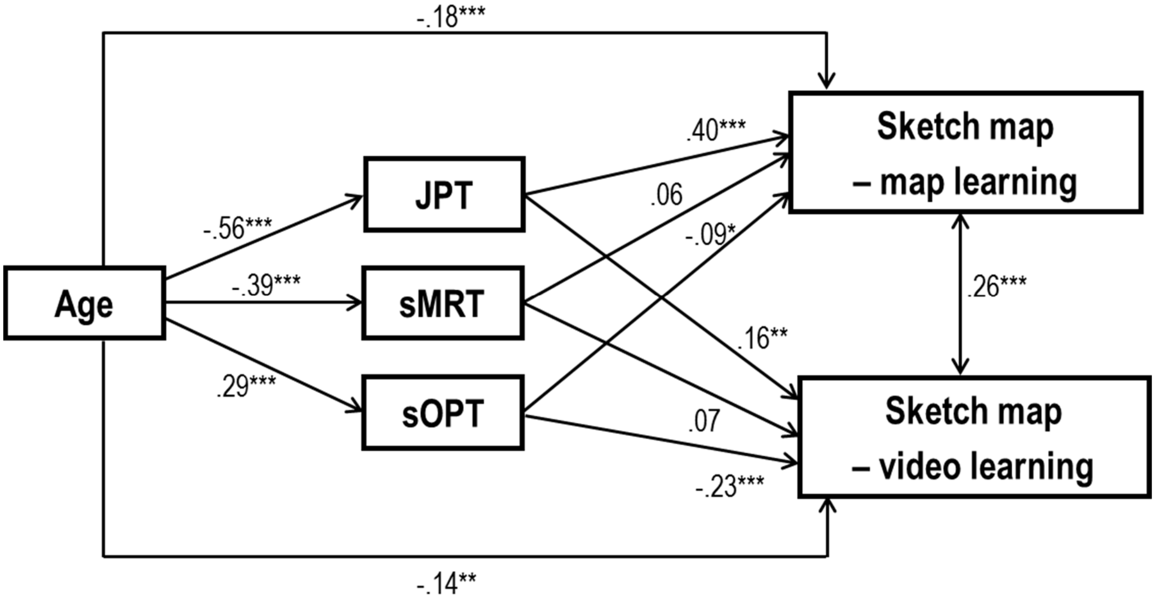
Figure 4.5. *Path model considering pointing errors as dependent variables.*



Note. Standardized solutions in the path model. **p* < .05, ***p* < .01, ****p* < .001.

Sketch map drawing task. In the model considering sketch map drawing accuracy as the dependent variable (see Figure 4.6.), significant direct relationships were found: i) between age and sketch map drawing accuracy after learning from the map or video; ii) between age and VSWM (JPT) and visuo-spatial abilities (sMRT and sOPT); and iii) between JPT and sOPT and sketch map drawing accuracy after map or video learning (see β and *p* values in Table 4.5.). Significant indirect relationships emerged too: age negatively influenced sketch map drawing accuracy through the mediation of VSWM (JPT) and perspective-taking ability (sOPT); see the corresponding β and *p* values in Table 3.5. The total variance accounting for sketch map drawing accuracy was 37% after map learning and 21% after video learning, and was explained by the significant direct relationship between VSWM and perspective-taking ability and sketch map drawing performance.

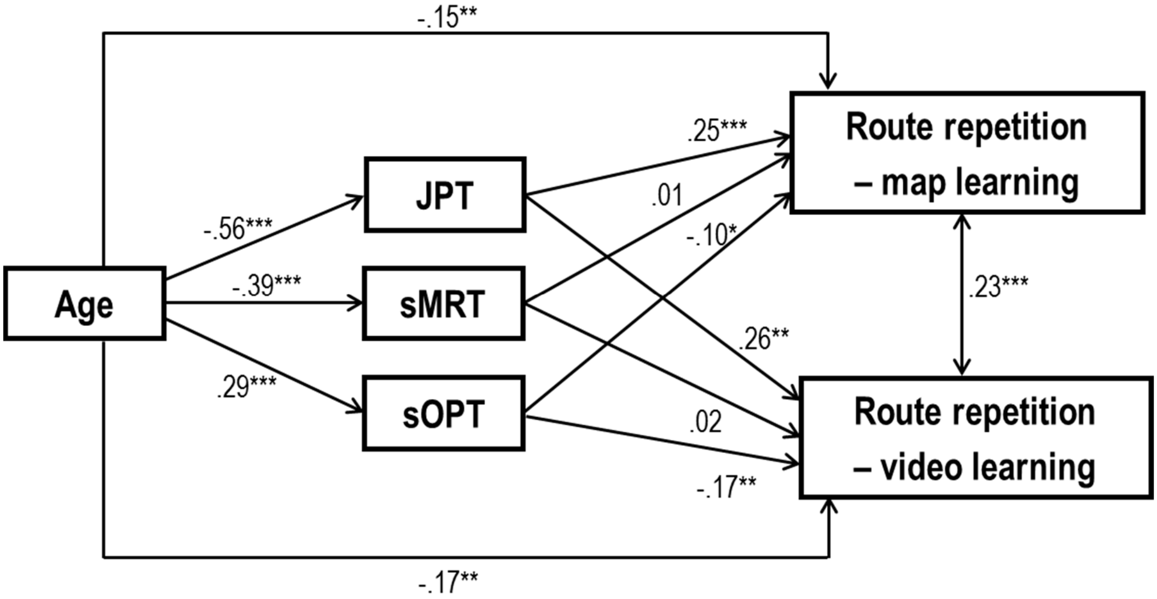
Figure 4.6. *Path model considering sketch map accuracy as the dependent variable.*



Note. Standardized solutions in the path model. **p* < .05, ***p* < .01, ****p* < .001.

Route repetition task. In the model considering route repetition accuracy as the dependent variable (see Figure 4.7.), significant direct relationships were found: i) between age and route repetition accuracy whatever the learning input; ii) between age and VSWM (JPT) and visuo-spatial abilities (sMRT and sOPT); and iii) between JPT and

Figure 4.7. *Path model considering route repetition accuracy as the dependent variable.*



Note. Standardized solutions in the path model. **p* < .05, ***p* < .01, ****p* < .001.

sOPT and route repetition accuracy after learning from the map or video (see β and *p* values in Table 4.5.). Significant indirect relationships emerged, with age negatively influencing route repetition accuracy through the mediation of JPT and sOPT (see corresponding β and *p* values in Table 4.5.). The total variance accounting for route repetition accuracy was 18% after map learning and 22%after route learning, and was explained by the significant direct relationship between VSWM and visuo-spatial abilities (sOPT) and route repetition performance.

Table 4.5. *Direct and indirect effects in the three models.*

		Pointing errors		Sketch map accuracy		Route repetition accuracy	
Effects		β	*p*	β	*p*	β	*p*
Direct	Age → Y - map learning	.04	.47	**-.18**	**< .001**	**-.15**	**.004**
	Age → Y - video learning	.01	.91	**-.15**	**.005**	**-.17**	**.002**
	Age → JPT	**-.56**	**< .001**	**-.56**	**< .001**	**-.56**	**< .001**
	Age → sMRT	**-.39**	**< .001**	**-.39**	**< .001**	**-.39**	**< .001**
	Age → sOPT	**.29**	**< .001**	**.29**	**< .001**	**.29**	**< .001**
	JPT → Y - map learning	**-.23**	**< .001**	**.40**	**< .001**	**.25**	**< .001**
	JPT → Y - video learning	-.03	.61	**.16**	**.008**	**.26**	**< .001**
	sMRT → Y - map learning	**-.23**	**< .001**	.06	.16	.01	.92
	sMRT → Y - video learning	**-.16**	**.005**	.07	.14	.02	.66
	sOPT → Y - map learning	**.16**	**.001**	**-.09**	**.036**	**-.11**	**.034**
	sOPT → Y - video learning	**.18**	**.001**	**-.23**	**< .001**	**-.17**	**.001**
Indirect	Age → JPT → Y - map learning	**.13**	**< .001**	**-.22**	**< .001**	**-.14**	**< .001**
	Age → JPT → Y - video learning	.02	.61	**-.09**	**.010**	**-.15**	**< .001**
	Age → sMRT → Y - map learning	**.09**	**< .001**	-.03	.17	.01	.92
	Age → sMRT → Y - video learning	**.06**	**.007**	-.03	.15	.01	.66
	Age → sOPT → Y - map learning	**.05**	**.003**	**-.03**	**.047**	**-.03**	**.045**
	Age → sOPT → Y - video learning	**.05**	**.004**	**-.07**	**< .001**	**-.05**	**.003**

Note. Significant relationships in bold type. Y = dependent variable.

4.4. Discussion

Study 3 examined the features of mental spatial representations by comparing two types of learning input, i.e., a map (an allocentrically-based stimulus) and a video (an egocentrically-based stimulus), in participants from 25 to 84 years old. The participants' individual visuo-spatial factors contributing to their mental representations were also investigated for each spatial recall task used. These tasks included a pointing task (which is inferential whatever the learning input), a sketch map drawing task (which resembles the map learning input), and a route repetition task (which resembles the video learning input). The results obtained are discussed along the lines of our two main objectives, which were to analyze: i) the role of age in the various tasks; and ii) the role of visuo-spatial factors in mental spatial representations.

4.4.1. Spatial recall by age groups after learning from the map or the video

Our results revealed age-related differences in all three tasks, with some differences within each task and each learning input. Overall, the effect of age consisted in that the old-old's performance was generally impaired in all types of task when compared with the young adults (from 25 to 44 years old). We confirmed the aging-related decline in people's spatial learning (Klencklen et al., 2012; Moffat, 2009), and that this impairment becomes more evident in later life (Barrash, 1994; Gazova et al., 2013). It is also noteworthy that young people from 25 to 44 years of age had the same performance in all the tasks, indicating that spatial learning abilities remain stable until people reach their fifties. Performance varied from 45 to 74 years of age, depending on the types of task considered. In inferential tasks, when participants were asked to imagine adopting different perspectives (i.e., the pointing tasks), the middle-aged and young-old adults performed equally well, and less well than the younger adults, indicating that performance in this type of task begins to deteriorate already from around fifty years old. In the sketch map drawing task, on the other hand, the age-related decline in performance seemed to develop a little later in life, beginning to emerge from 55 years of age and then remaining stable up to age 74, after which it was further impaired. The performance of the age group in between (from 45 to 54 years old) did not differ to any statistically significant degree from the younger or the next oldest group (55- to 64-year-olds). In the route repetition task, a decline in performance was already observable from 45 years old, and became worse in later life (in people in their seventies). These findings consequently give the impression that it could be important to study middle-aged adults (Gyselinck et al., 2013) in the spatial learning domain in an effort to ascertain why spatial learning processes start to decline and how to contain or compensate for such losses (Lövdén et al., 2012).

The age-related differences seen over the adult lifespan can be better qualified, however, if we compare different learning inputs (the map vs. the video). First, there was evidence of a general benefit to accuracy when the task used to test it was in format resembling that of the learning phase (Yamamoto & DeGirolamo, 2012), i.e., sketch map drawing accuracy was better after learning from the map than from a video, and performance in the route repetition task was better after learning from the video. Learning from the map was also an advantage when it came to solving the pointing task. Maps generate configural knowledge, showing landmarks and their relationships, and this benefits our ability to imagine adopting different perspectives in the environment (Richardson et al., 1999). On the other hand, there were remarkable age-related differences when participants were administered the pointing task after learning from the map, but not if they had learned from the video. This suggests that younger people are better able than older people to draw advantage from seeing the layout of landmarks as a whole (on the map). This is in line with other findings to suggest that older people do not always benefit from having a map (Borella, Meneghetti, Muffato, & De Beni, 2014; Sjölinder, Höök, Nilsson, & Andersson, 2005). This advantage for the younger groups alone was seen in the sketch map drawing task after map learning too, since young adults were more accurate than any of the other groups, whereas after learning from the video they only performed better than the oldest groups. This was not the case in route repetition performance, where age-related differences were unaffected by the learning input. This means that the advantage for the young adults did not depend on the resemblance between the formats of the learning and test phases – otherwise the same advantage would have been found in the route repetition task after learning from the video. We surmise that young adults' performance is better after learning from a map (e.g., Coluccia, 2008) because this format enables them to develop a more efficient mental spatial representation.

But, to better understand mental spatial representation at different ages, we need to consider individual visuo-spatial factors too, as discussed below.

4.4.2. Spatial recall and visuo-spatial factors

The role of individual visuo-spatial factors was investigated with path models to see how these variables influenced the relationship between age and spatial recall task performance, after learning from a map or a video. The individual visuo-spatial factors considered were: VSWM, assessed using an active task (i.e., JPT); rotation ability, assessed with the MRT; and perspective-taking ability, assessed with the OPT. The latter two are different higher-level abilities (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001), that were considered separately here in order to pinpoint their specific role in spatial recall performance. First of all, we confirmed that these visuo-spatial factors decrease with increasing age. Direct relationships were found between age and VSWM, MRT and OPT (Borella, Meneghetti, Ronconi, & De Beni, 2014; Techentin, Voyer, & Voyer, 2014).

For all the spatial tasks (i.e., pointing, sketch map drawing and route repetition, each after map and video learning), we found an influence of some or all of the above-mentioned visuo-spatial factors influencing the effect of age on spatial performance, and demonstrating their importance in supporting spatial learning (e.g., Kirasic, 2000; Meneghetti, Borella, Muffato, Pazzaglia, & De Beni, 2014). The visuo-spatial factors considered here had a different impact on performance in each task depending on the learning input (map or video), as briefly summarized below:

i) In the pointing task, for both learning inputs, the role of age was only relevant through the influence of visuo-spatial factors, which mediated the relationship between age and pointing performance. More variance was explained, however, by performance after learning from the map than from the video. Individual visuo-spatial factors had a stronger influence on pointing performance after learning from the map than from the video. In addition, VSWM, rotation and perspective-taking abilities were all found relevant in the relationship between age and pointing performance after learning from the map, but only rotation and perspective-taking abilities were implicated after learning from the video.

ii) In the sketch map drawing task, significant direct relationships were found between age and performance (for both learning inputs), but they were attenuated by indirect relationships, with individual visuo-spatial factors partially mediating the relationship between age and sketch map drawing performance. The same VSWM and perspective-taking abilities were involved in sketch map drawing accuracy, but the influence of the former was greater after map learning, and that of the latter after video learning. Overall, the impact of this partial mediation by individual visual-spatial factors on sketch map drawing performance was stronger after learning from the map.

iii) In the route repetition task, there was again a significant direct relationship between age and performance whatever the learning input involved, and indirect relationships with VSWM and perspective-taking ability partially mediating the relationship between age and route repetition task performance. VSWM and perspective-taking ability proved equally important whichever learning input was used, with a stronger impact of VSWM.

Overall, these findings confirm the important influence of people’s visuo-spatial abilities on their mental spatial representations (Allen, Kirasic, Dobson, Long, & Beck, 1996; Hegarty et al., 2006), also in combination with the role of age (Kirasic, 2000; Meneghetti et al., 2014), throughout the adult lifespan (Meneghetti, Borella, Pastore, & De Beni, 2014). In particular, visuo-spatial factors seemed important in mediating the relationship between age and spatial recall, and their impact differed depending on the type of recall task and the type of input. VSWM, measured with an active task (JPT) in our study, was relevant in all tasks (Borella et al., 2014; Coluccia, Bosco, & Brandimonte, 2007; Mitolo et al., 2015), and for all learning inputs, except for pointing task performance after learning from the video. VSWM therefore seems a crucial basic cognitive resource supporting spatial learning performance, repeating a route or recalling configural knowledge in a sketch map drawing task, irrespective of the learning input. Higher-level visuo-spatial abilities (rotation and perspective-taking abilities) are needed too, especially the latter, and these higher-level visuo-spatial abilities proved particularly important in mediating the relationship between age and pointing performance regardless of the learning input used. This confirms that having to imagine adopting different views in an environment demands the ability to mentally rotate a view and see things from a different angle (Meneghetti, Muffato, Varotto, & de Beni, 2016; Richardson et al., 1999), considering the adult lifespan. Although these abilities decline with aging (e.g., Techentin et al., 2014), they are useful in inferential spatial tasks for as long as they are preserved.

Individual visuo-spatial abilities thus influence the relationship between age (considered as a continuum from youth to old age) and spatial task performance, and the extent of their involvement depends on the type of task and the learning input.

5. General conclusions

The general aims of this dissertation project were to analyze mental spatial representations derived from common spatial learning inputs, such as a map and/or navigation, in relation to the role of age and of individual visuo-spatial factors.

Concerning the role of age, published studies have demonstrated that spatial learning performance declines with age (Klencklen et al., 2012; Moffat, 2009), and that it becomes impaired whether an environment is learned from a map (e.g., Borella et al., 2014; Thomas, Bonura, & Taylor, 2012) or from navigation (Barrash, 1994; Taillade et al., 2016). Some research has suggested, however, that older adults' performance can vary (e.g., Jansen et al., 2009; Wiener et al., 2013) depending, for instance, on the type of task used to test spatial recall (Cushman et al., 2008). There is still a paucity of knowledge as regards the comparison between map reading and navigation as a means of learning spatial information, but some evidence suggests that older adults benefit from using a map rather than navigating a route (Yamamoto & DeGirolamo, 2012). The present research project aimed to contribute to what is known in this field by systematically analyzing the influence of age on mental spatial representations, considering different types of learning input (map and/or navigation) and administering different types of spatial recall task, as suggested in the model developed by Hegarty et al. (2006).

This model (Hegarty et al., 2006) also highlighted the influence of individual visuo-spatial factors on mental spatial representations. Research has shown that basic spatial abilities, such as VSWM, and cognitively higher-level visuo-spatial abilities, such as mental rotation and perspective-taking, are used for spatial learning by older adults too (e.g., Kirasic, 2000; Meneghetti, Borella, Muffato, et al., 2014), and may be core factors in explaining variability in spatial learning performance. These abilities were analyzed here in combination with the role of age, type of learning input, and type of recall task.

In particular, this dissertation project analyzed the features of mental spatial representations:

i) after learning an environment from a map; recall was tested with map drawing, sketch map, and pointing tasks, in young, young-old and old-old participants (Map learning - Study 1);

ii) after direct navigation in an environment; recall was tested using route repetition, map drawing, and pointing tasks, in young and young-old participants (Navigation learning - Study 2);

iii) after learning from a map or a video; recall was tested using route repetition, sketch map drawing, and pointing tasks, in participants of all ages across the adult lifespan (Map and video route learning - Study 3);

and also examined the contribution of VSWM and visuo-spatial (rotation and perspective-taking) abilities.

In all three studies, participants took part in two sessions. In the first, they performed a VSWM task (i.e., JPT, De Beni et al., 2008; adapted from Richardson & Vecchi, 2002), a task measuring their rotation ability (sMRT, De Beni et al., 2014; adapted from Vandenberg & Kuse, 1978), and a perspective-taking task (sOPT, De Beni et al., 2014, adapted from Kozhevnikov & Hegarty, 2001). In the second session, they learned an environment from a map and/or navigation, then completed a series of recall tasks.

Concerning the role of age, the results of all three studies indicated that young people produce more efficient mental spatial representations than older people, and that the quality of these representations is also influenced by the type of learning input and by the type of task used to assess their recall. For instance, in Study 1 (learning from maps) age-related differences after learning from a map were found for tasks that involved manipulating spatial information (pointing and map drawing tasks), whereas the young-old adults performed as well as the young when they could take advantage of having a task to solve in the same format as they had used in the learning phase (a sketch map task), and when they were given cues. The old-old's performance remained worse than that of the other two age groups for all types of task, however. In Study 2 (learning from navigation), although the role of age was apparent in all the tasks, the young-old's performance was adequate in recalling landmarks learned from direct navigation, and they were as capable as the young adults in deciding which way they had to turn in a route repetition task. Finally, the results of Study 3 (learning a route from a map vs. a video) suggest that spatial learning deteriorates particularly in later life (e.g., Uttl & Graf, 1993), in people in their seventies (as found by Barrash, 1994), but this process seems to start already in their fifties for some spatial recall tasks; this would point to the importance of research in this area paying more attention to the middle-aged (Gyselinck et al., 2013).

As for the role of individual visuo-spatial abilities, the three studies highlighted their relevance in supporting mental spatial representations. After learning from a map (Study 1), their role is more evident in tasks that involve manipulating spatial information, such as freely drawing a map of the environment learned, and imagining adopting a position counter-aligned to the one learnt. Similarly, after navigating directly in an environment (Study 2), the role of VSWM and visuo-spatial abilities was especially important in pointing task performance. Finally, in Study 3, individual visuo-spatial factors were newly found to influence (and in some cases mediate) the relationship between age and spatial learning performance for all types of task, albeit to a different degree depending on the type of learning input used. Table 5.1 contains a schematic outline of the main findings.

Overall, our studies confirm the connections between aging, visuo-spatial abilities and spatial learning. Age-related differences depend on the type of task used to test spatial learning, and individual visuo-spatial factors influence performance differently, depending on the type of task administered, and partly on the type of learning input used.

These findings expand our knowledge in the spatial cognition and aging domains. As regards theoretical models adopted in the spatial cognition domain, these studies confirm that individual visuo-spatial factors defined as small-scale cognitive abilities predict spatial learning, which is considered a large-scale ability (Hegarty et al. 2006; Montello, 1998; Wolbers & Hegarty, 2010). We demonstrated the fundamental importance of VSWM and visuo-spatial abilities in supporting spatial learning not only in the young, but across the adult lifespan, and into old age. This becomes particularly evident when spatial information has to be manipulated or inferred, as in the more demanding tasks like the pointing task.

Our results also show that mental spatial representations are influenced by individual visuo-spatial factors. This is consistent with the model devised by Carlson et al. (2010), in which the cognitive map intersects with visuo-spatial abilities (although Carlson et al. considered indoor spatial representations). In fact, Carlson et al. point to the

Table 5.1. Overview of the methods (participants, learning inputs, recall tasks, individual visuo-spatial abilities) and results of all three studies.

<table>
<tr><th></th><th>Participants' age groups</th><th>Type of spatial input</th><th>Spatial recall tasks</th><th>Individual visuo-spatial abilities</th><th colspan="7">Main results</th></tr>
<tr><td rowspan="5">Study 1</td><td rowspan="5">Y vs. Y-O vs. O-O</td><td rowspan="5">Map learning</td><td rowspan="5">- Map drawing task
- Sketch map task
- Pointing task</td><td rowspan="5">VSWM
Visuo-spatial abilities
Learning strategies</td><td><i>The role of:</i></td><td colspan="2"><i>Sketch map</i></td><td colspan="2"><i>Map drawing</i></td><td colspan="2"><i>Pointing</i></td></tr>
<tr><td><i>Age</i></td><td colspan="2">(Y = Y-O) > (O-O)</td><td colspan="2">Y > (Y-O = O-O)</td><td colspan="2">Y > (Y-O = O-O)</td></tr>
<tr><td><i>VSWM</i></td><td colspan="2"></td><td colspan="2">✓</td><td colspan="2">✓</td></tr>
<tr><td><i>Visuo-spatial abilities</i></td><td colspan="2"></td><td colspan="2">✓</td><td colspan="2">✓ in counter-aligned pointing</td></tr>
<tr><td><i>Learning strategies</i></td><td colspan="2"></td><td colspan="2">✓</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Study 2</td><td rowspan="4">Y vs. Y-O</td><td rowspan="4">Route learning from direct navigation</td><td rowspan="4">- Route repetition
- Map drawing task
- Pointing task</td><td rowspan="4">VSWM
Visuo-spatial abilities</td><td><i>The role of:</i></td><td colspan="2"><i>Route repetition</i></td><td colspan="2"><i>Map drawing</i></td><td colspan="2"><i>Pointing</i></td></tr>
<tr><td><i>Age</i></td><td colspan="2">Y > Y-O in landmark identification
Y = Y-O in choosing turning points</td><td colspan="2">Y > Y-O in global accuracy
Y > Y-O in missing landmarks</td><td colspan="2">Y > Y-O</td></tr>
<tr><td><i>VSWM</i></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">✓</td></tr>
<tr><td><i>Visuo-spatial abilities</i></td><td colspan="2">✓</td><td colspan="2">✓</td><td colspan="2">✓</td></tr>
<tr><td rowspan="6">Study 3</td><td rowspan="6">Adult lifespan from 25 to 84 years old</td><td rowspan="6">Route learning from map vs. video</td><td rowspan="6">-Route repetition
- Sketch map drawing task
- Pointing task</td><td rowspan="6">VSWM
Visuo-spatial abilities</td><td></td><td colspan="2"><i>Route repetition</i></td><td colspan="2"><i>Map drawing</i></td><td colspan="2"><i>Pointing</i></td></tr>
<tr><td><i>The role of:</i></td><td><i>Map</i></td><td><i>Video</i></td><td><i>Map</i></td><td><i>Video</i></td><td><i>Map</i></td><td><i>Video</i></td></tr>
<tr><td><i>Age</i></td><td colspan="2">✓</td><td colspan="2">✓</td><td colspan="2">✓</td></tr>
<tr><td><i>VSWM</i></td><td>✓ (partial mediation)</td><td>✓ (partial mediation)</td><td>✓ (partial mediation)</td><td>✓ (partial mediation)</td><td>✓ (mediation)</td><td></td></tr>
<tr><td><i>Rotation ability</i></td><td></td><td></td><td></td><td></td><td>✓ (mediation)</td><td>✓ (mediation)</td></tr>
<tr><td><i>Perspective-taking ability</i></td><td>✓ (partial mediation)</td><td>✓ (partial mediation)</td><td>✓ (partial mediation)</td><td>✓ (partial mediation)</td><td>✓ (mediation)</td><td>✓ (mediation)</td></tr>
</table>

Note. Y, young adults; Y-O, young-old adults; O-O, old-old adults; =, groups' performance was the same; >, one group performed better than others; ✓, an effect of a variable was found.

importance of how an environment is structured as another factor intersecting with the cognitive map and individual characteristics. Cognitive maps are therefore influenced not only by individual differences, but also by the features of an outdoor or indoor environment. This issue was not considered in the present dissertation, and remains to be elucidated in future research. What was newly demonstrated here is the importance of simultaneously considering internal factors (such as individual visuo-spatial abilities) and external factors (such as types of learning input and types of recall task) when analyzing mental spatial representations. The present results newly showed that visuo-spatial abilities still play an important part in predicting spatial learning performance in older adults, albeit with some differences relating to learning input and recall test method, which assess different aspects of a mental spatial representation.

These results are line with spatial cognition models (Carlson et al., 2010; Hegarty et al. 2006; Wolbers & Hegarty, 2010), but are consistent with aging models too, and particularly with the model that sees aging as a multidimensional and multidirectional stage of life (Baltes & Staudinger, 2000). Some skills become impaired and may be lost, but there are also strengths that older adults can use to compensate for their losses. We suggest that, even when they begin to decline, individual visuo-spatial abilities should still be seen as strengths (e.g., Techentin et al., 2014) that continue to support people’s spatial learning throughout their lives.

The present results have some implications relating to this aspect. For instance, our results concerning individual visuo-spatial factors suggest that prevention measures such as VSWM training might be useful (Lövdén et al., 2012; Nemmi, Boccia, & Guariglia, 2017). Training people’s visuo-spatial skills could protect against the effects of an impaired hippocampus (Lövdén et al., 2012). Another practical implication of our findings lies in that spatial learning performance could be measured for clinical purposes, to distinguish for instance between normal, healthy aging and the early stages of Alzheimer’s disease, in which some of the first symptoms relate to the spatial domain (Iachini et al., 2009; Klencklen et al., 2012). Young-old adults with an impaired performance in a sketch map task after learning from a map may have difficulty in organizing spatial information, and this should prompt further investigations; the same applies to young-old adults revealing weaknesses in route learning after navigating an environment. These are just examples of how measuring these aspects might be useful in clinical assessments, and this is an area that warrants further investigation.

Other open issues emerge when we consider the limitations of the present studies. For instance, the only individual factors considered here were age and visuo-spatial abilities, while other personal characteristics could influence mental spatial representations too. Future research could investigate the role of gender and formal education, for instance, the former known to influence spatial learning performance (Coluccia & Louse, 2004), and the latter to affect cognitive performance in a broader sense (e.g., Noroozian, Shakiba, & Iran-Nejad, 2014). Other interesting personal visuo-spatial factors to consider include individual spatial preferences, sense of direction, and spatial anxiety (Lawton et al., 1994), which are self-report measures relating to a person's experience in the spatial domain. These individual characteristics could relate to spatial performance in some way, helping to explain spatial learning differences (e.g., Hegarty et al., 2006; Weisberg et al., 2014; Wolbers & Hegarty, 2010). In addition, two types of learning input were tested (maps and navigation) in the present studies, but their role in combination (when finding a place in a real-life environment with the aid of a map) was not explored. This is a common experience in daily life, however, so future research should analyze in depth the transfer of knowledge gained from a map by having study participants move around in an environment after seeing a map.

In conclusion, the present dissertation project sheds light on people's mental spatial representations and how they change with aging, confirming that spatial learning is a complex matter. External factors, such as the learning format used and the recall tasks administered, and internal factors such as age and individual visuo-spatial factors, combine together to influence mental spatial representation processes and how they change over time.

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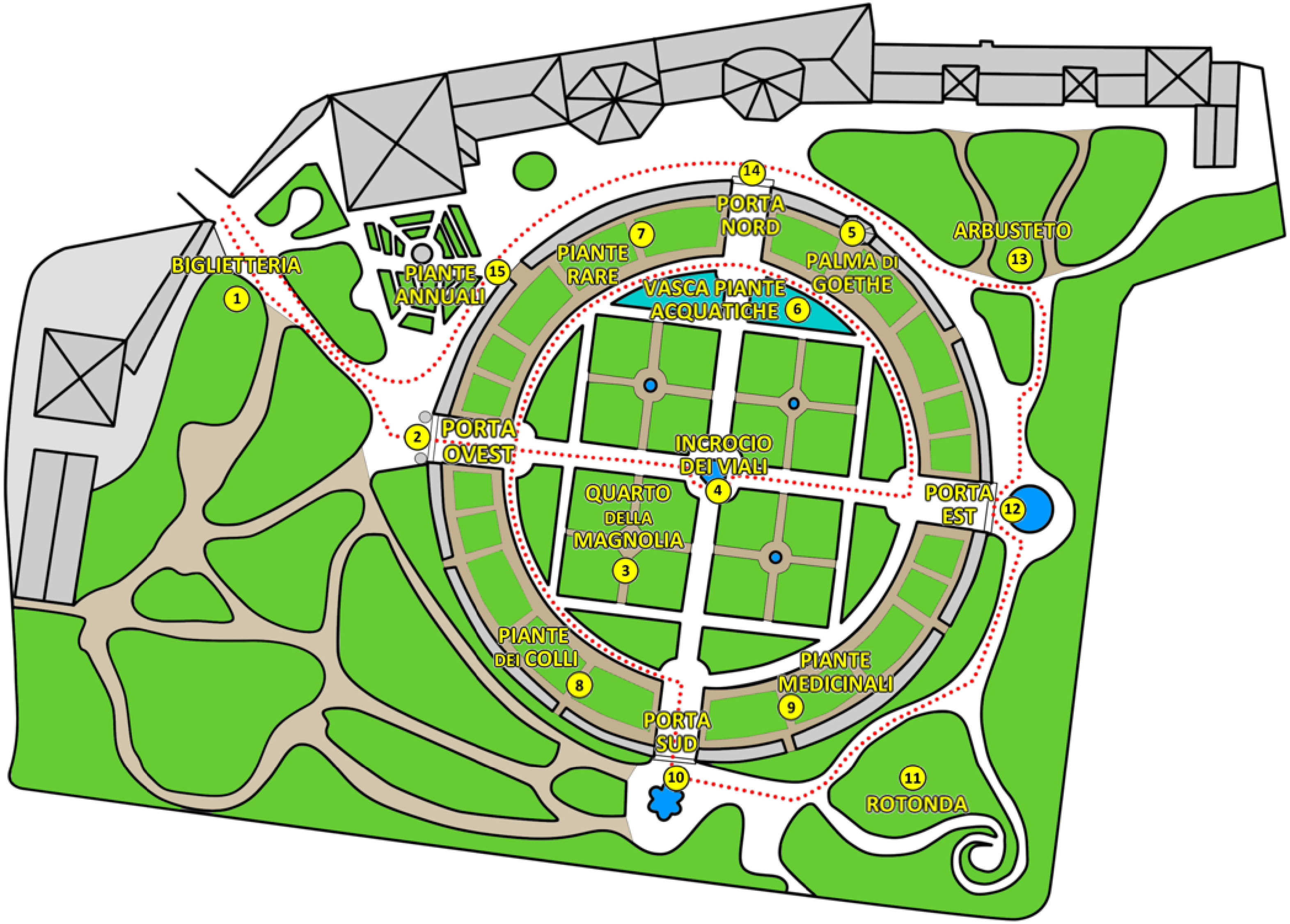
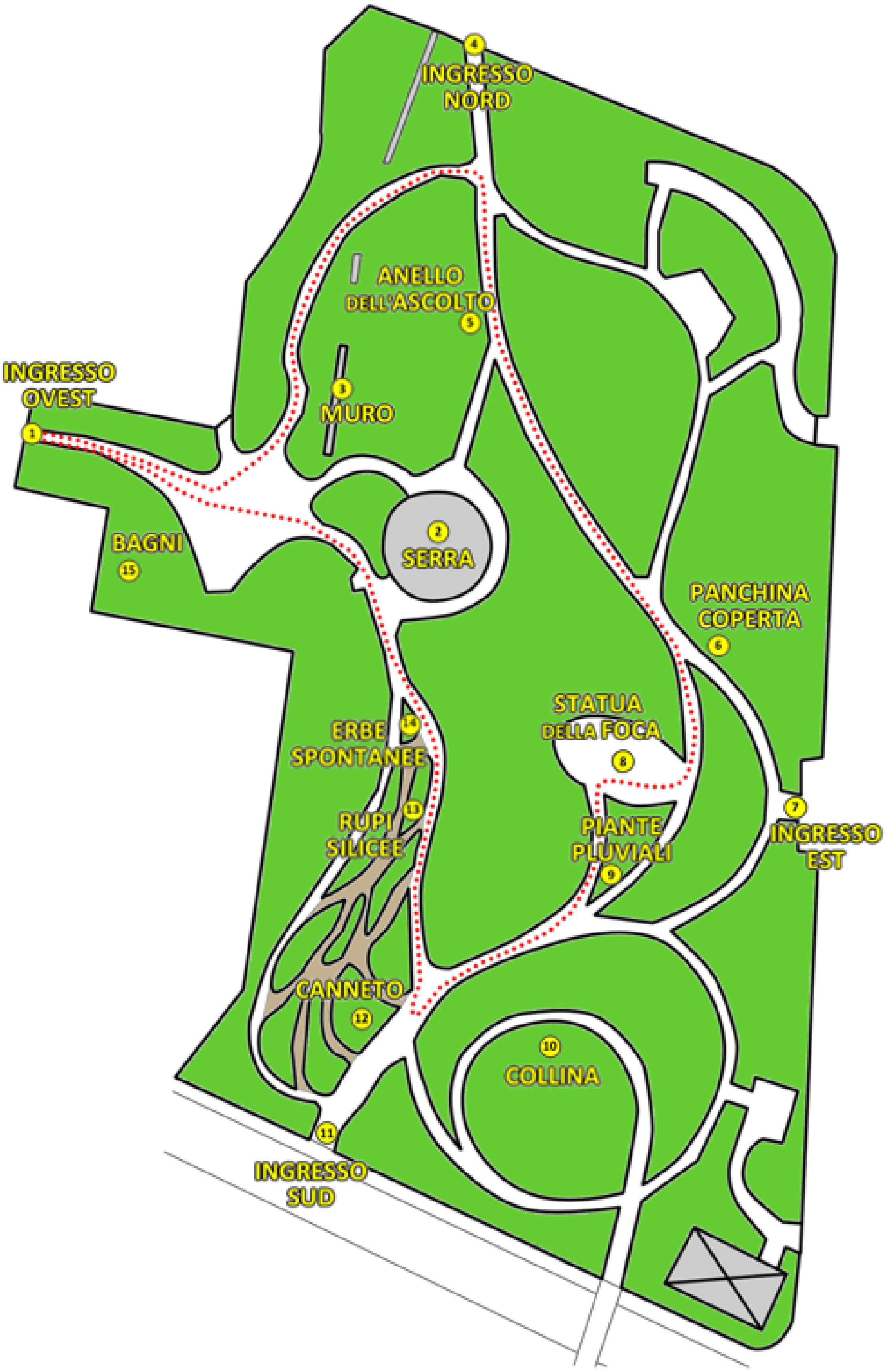
Appendix A: Environments

Botanical garden



“Europe” park


4
INGRESSO NORD
ANELLO DELL'ASCOLTO
5
INGRESSO OVEST
1
3
MURO
2
SERRA
BAGNI
15
PANCHINA COPERTA
6
STATUA DELLA FOCA
8
ERBE SPONTANEE
14
RUPI SILICEE
13
PIANTE PLUVIALI
9
7
INGRESSO EST
CANNETO
12
10
COLLINA
11
INGRESSO SUD