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SPATIAL ABILITIES: FROM THEIR ASSESSMENT TO THEIR IMPROVEMENT IN OLDER ADULTS

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Please refer to the section 6.1 "Summary of the findings and their implications" for a summary of the present dissertation.

“Consider well the seed that gave you birth:

you were not made to live as brutes,

but to follow virtue and knowledge.”

Ulysses, Dante Alighieri's Inferno (Hell), canto (poem) XXVI

Introduction

Within the spatial cognition domain, moving around efficiently, getting to places and learning new routes, are among the spatial abilities of day-to-day living, which have been shown to be sensitive to age-related decline (e.g., Klencklen, Deprés, & Dufour, 2012). There is now growing evidence that, among others, individuals' visuo-spatial factors play a role in explaining the age-related differences between young and older adults' environment learning skills (e.g., Hegarty, Montello, Richardson, Ishikaw, & Lovelace, 2006; Meneghetti, Borella, Pastore, & De Beni, 2014; Muffato, Meneghetti, & De Beni, 2016; 2018; 2019). Individuals' visuo-spatial factors (see Hegarty et al., 2006) refer to objective visuo-spatial abilities, i.e., high-order visuo-spatial skills, such as rotation ability (e.g., Uttal et al., 2013) and processing resources such as visuo-spatial working memory (VSWM; Baddeley, 2012). Another individual visuo-spatial factor is represented by self-assessed visuo-spatial inclinations toward environment-related tasks (e.g., De Beni, Meneghetti, Fiore, Gava, & Borella, 2014). Objective visuo-spatial abilities and self-assessed visuo-spatial inclinations have shown age-related changes with different trajectories: the former decline with increasing age (e.g., Borella, Meneghetti, Ronconi, & De Beni, 2014; De Beni et al., 2014; Mammarella, Borella, Pastore, & Pazzaglia, 2013), while the latter, in contrast, do not seem sensitive to age-related decline (e.g., Borella et al., 2014; De Beni et al., 2014).

Given that the age-related changes experienced by older adults in their spatial abilities (environmental and visuo-spatial ones) might limit their safety and autonomy, with detrimental consequences for their active aging and quality of life, the present dissertation aimed to further explore the age-related differences between young and older adults' spatial skills, focusing on different, though complementary, issues. One aim was to ascertain the role of some individual characteristics in influencing individuals' visuo-spatial factors. Further aims were to identify, on the one hand, new interactive tasks to assess visuo-spatial abilities in older adults, and, on the other hand, new procedures to support/improve both spatial (route) learning and visuo-spatial skills in aging.

Chapter 1 presents the theoretical framework used to define individuals' visuo-spatial factors and their relationship with environment learning, considering the age-related differences between young and older adults as well the role of other individual characteristics (i.e., personality) in influencing them. Moreover, the use of a new interactive task for the assessment of VSWM is discussed. Finally, the chapter presents previous evidence on the benefits of procedures or cognitive interventions aimed at improving spatial abilities, which offers insights for the development of new effective ways to support/improve them in older adults. Chapter 2 describes the first study aimed to further investigate whether personality influences young and older adults' objective visuo-spatial abilities and self-assessed visuo-spatial inclinations. Chapter 3 illustrates a second study that aimed to newly assess VSWM in young and older adults with the backward Walking Corsi Test (WalCT), an extended version of the backward Corsi Blocks Task (CBT) which involves recalling sequences of spatial locations while moving around in a controlled setting. The specific contribution of the backward WalCT, beyond that of the classic CBT, in mediating age-related effects on rotation ability was analyzed. Chapter 4 describes a third study which explored the benefit of practicing and using an imagery strategy to support spatial (route) learning and recall both in young and, for the first time, in older adults. Chapter 5 concerns a fourth study which explored in a sample of healthy older adults whether training VSWM, combining practice with tasks in which participants are required to move around in a controlled setting (similar to the WalCT) and VSWM tasks yielded in a classic tablet-based modality (similar to the CBT), promotes not only specific training gains (in VSWM tasks similar to the ones trained), but also transfer effects to untrained measures of rotation ability. Table 1 briefly summarizes the content of the four studies. The studies described were approved by the Ethical Committee for Psychological Research at the University of Padova.

Finally, Chapter 6 contains a general discussion of the relevant results and conclusions drawn on the findings of the studies conducted.

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

General aims	Sample characteristics	Materials & Procedure		
Study 1: Exploring the association between personality (traits and facets) and individuals' visuo-spatial factors	70 YA (age range: 18-35 years) 70 healthy OA (age range: 65-75 years)	All participants completed, in two individual sessions:		
		Personality	Objective visuo-spatial abilities	Self-assessed visuo-spatial inclinations
		The Big Five Questionnaire-60 (Caprara et al., 2006).	- VSWM tasks: the backward Corsi Blocks Task (Corsi, 1972), the Pathways Span Task (adapted from Mammarella et al., 2008), the Puzzle test (De Beni et al., 2008). - Rotation ability measures: the short Mental Rotations Test and the short Object Perspective Test (De Beni et al., 2014).	The Attitude to Orientation Task and the Spatial Anxiety scales (De Beni et al., 2014).
Study 2: Using a new VSWM measure, i.e., the backward Walking Corsi Test, to explain age-related effects on rotation ability	70 YA (age range: 18-35 years) 56 healthy OA (age range: 65-75 years)	All participants performed, in two individual sessions:		
		New VSWM measure	Classic visuo-spatial measures	Self-assessed visuo-spatial inclinations
		The Walking Corsi Test (Piccardi et al., 2019)	- VSWM tasks: the backward Corsi Blocks Task (Piccardi et al., 2019; adapted from Corsi, 1972), the Pathways Span Task (adapted from Mammarella et al., 2008), the Puzzle test (De Beni et al., 2008). - Rotation ability measures: the short Mental Rotations Test and the short Object Perspective Test (De Beni et al., 2014).	The Attitude to Orientation Task and the Spatial Anxiety scales (De Beni et al., 2014).

<table>
<tr>
<td rowspan="3">Study 3: Exploring the beneficial effect of practicing and using an imagery strategy to support spatial (route) learning</td>
<td rowspan="3">40 YA
(age range: 18-35 years)
40 healthy OA
(age range: 65-75 years)</td>
<td colspan="6">Participants learned a path from a video in an individual session.</td>
</tr>
<tr>
<td colspan="2">Instructions phase</td>
<td colspan="2">Route learning phase</td>
<td colspan="2">Recall phase</td>
</tr>
<tr>
<td colspan="2">Twenty participants of each age group were taught to use an imagery strategy (SG).
The others performed alternative activities, i.e., completing questionnaires on memory sensitivity and psychological well-being (CG).</td>
<td colspan="2">All participants learned a new path.
Participants in the SGs were advised to use the imagery strategy to memorize it, while the CGs received no specific instructions.</td>
<td colspan="2">All participants were asked to recall the order and location of the landmarks they had seen along the path.</td>
</tr>
<tr>
<td rowspan="6">Study 4: Training VSWM combining the practice with VSWM tasks entailing a greater amount of interaction with the real-world environment, i.e., to move around in a controlled setting, and VSWM tasks administered in a classic modality, i.e., on tablet.</td>
<td rowspan="6">12 healthy OA
(age range: 65-75 years)</td>
<td colspan="6">Participants were randomly assigned to:</td>
</tr>
<tr>
<td colspan="3">Training Group</td>
<td colspan="3">Active Control Group</td>
</tr>
<tr>
<td colspan="3">Involved for 6 individual sessions in a VSWM training entailing practicing both on tablet and moving in a controlled setting.</td>
<td colspan="3">Involved for 6 individual sessions in alternative activities (i.e., find the differences and walk the line tasks).</td>
</tr>
<tr>
<td colspan="6">Participants were also involved in four other individual sessions (i.e., pre- and post-test sessions) to complete a battery of visuo-spatial measures for the assessment of training benefits:</td>
</tr>
<tr>
<td colspan="3">Specific training gains</td>
<td colspan="3">Transfer effects</td>
</tr>
<tr>
<td colspan="3">- The backward Corsi Blocks Task (adapted from Piccardi et al., 2019)
- The backward Walking Corsi Test (adapted from Piccardi et al., 2019)</td>
<td colspan="3">- VSWM measure: the Pathways Span Task (adapted from Mammarella et al., 2008);
- Rotation ability measures: the Mental Rotations Test (Vandenberg & Kuse, 1978) and the Object Perspective Test (Kozhevnikov & Hegarty, 2001).</td>
</tr>
</table>

Note. VSWM: visuo-spatial working memory; YA: young adults; OA: older adults; SG: strategy group; CG: control group.

1. Assessing and supporting spatial abilities in aging: insights from the literature.

1.1 Environment learning and individuals' visuo-spatial factors: theoretical framework.

Successful everyday navigation is a particularly complex behavior that requires the integration of different types of spatial information, relying on a range of perceptual, mnemonic, processing resources and abilities (see Lester, Moffat, Wiener, Barnes, & Wolbers, 2017; Montello, 2005; Wolbers & Hegarty, 2010). Spatial navigation is indispensable not only for finding the way in familiar environments, but also for planning routes to distant locations and for learning new routes by moving through a space to a given destination (Montello, 2009). Individuals can acquire spatial knowledge either directly, by navigating the environment, or by looking at a map (Richardson, Montello, & Hegarry, 1999), as well as using verbal information (environment descriptions; see Gyselinck & Meneghetti, 2011, for a review) or symbolic sources such as visual inputs (virtual navigation; see Hegarty, Montello, Richardson, Ishikaw, & Lovelace, 2006; Montello, Waller, Hegarty, & Richardson, 2004, for a review). Learning environmental information leads to the construction of mental representations, i.e., cognitive maps representing landmarks and their relative locations (Tolman, 1948; Wolbers & Hegarty, 2010). Such internal representations deriving from exposure to an environment cannot be measured directly (e.g., Hegarty et al., 2006). Different outcome measures, however, allow the analysis of how environmental information is stored and organized in memory (Golledge, 1999; Hegarty et al., 2006). Spatial recall tasks involve, for example, recalling the landmarks encountered and their relationships, retracing the route learned, judging distances and directions, or drawing a map of the environment (e.g., Hegarty et al., 2006).

It is now widely accepted that the ability to integrate spatial information in the environment representation, apart from external factors (related to the type of learning input and the type of recall tasks considered), is also influenced by individuals' visuo-spatial factors, which become a source of variability in spatial learning. The model by Hegarty et al. (2006) serves as a framework in this sense: the authors analyzed the ability to depict an environment by administering several spatial recall tasks, such as direction and distance estimation and map drawing, after participants had learned a route from direct or virtual exploration. Using a structural equation modeling approach, the authors demonstrated that the accuracy in forming and using mental representations of the environment acquired was predicted by individuals' visuo-spatial abilities needed to generate, retain and process visuo-spatial information -here measured by means of the Embedded Figures Test (Oltman, Raskin, & Witkin, 1971), the Mental Rotations Test (Vandenberg & Kuse, 1978) and the Arrow span test (Shah & Miyake, 1996), which can be called objective visuo-spatial abilities, and by their self-assessed visuo-spatial inclinations -here measured using the Santa Barbara Sense of Direction questionnaire (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002).

Such objective visuo-spatial abilities (assessed with objective visuo-spatial tasks) and self-assessed visuo-spatial inclinations (assessed with questionnaires), thus, represent two distinct -though related- individual visuo-spatial factors (Hegarty et al., 2006).

The objective visuo-spatial abilities include, in turn, high-order visuo-spatial abilities such as, among others, rotation ability, i.e., the ability to turn two- or three-dimensional objects in one's mind, or to adopt different views (Uttal et al., 2013). They also encompass processing resources like visuo-spatial working memory (VSWM), i.e., the memory system devoted to maintaining and processing visuo-spatial information (Baddeley, 2012). It is worth mentioning that, though rotation ability and VSWM represent two distinct visuo-spatial sub-abilities, they have been shown to share a common part of the variance and can be grouped as a single visuo-spatial factor (Hegarty et al., 2006). Indeed, it has been demonstrated that VSWM processing resources used to maintain and operate on visuo-spatial information are involved in complex visuo-spatial tasks demanding rotation ability (e.g., Bruyer & Scailquin, 1998; Cornoldi & Mammarella, 2008; Hegarty & Waller, 2005; Hyun & Luck, 2007; Wang & Carr, 2014; Wang, Bolin, Lu & Carr, 2018; Meneghetti et al., 2016b). The relationship between VSWM and rotation ability has also been underscored by the results of neuroimaging studies showing similar brain regions being activated when participants completed VSWM and rotation tasks (e.g., Christie et al., 2013; Levin, Mohamed & Platek, 2005).

Self-assessed visuo-spatial inclinations, on the other hand, refer to how individuals assess their own inclination to approach and move in the environment. They encompass, for example, individuals' self-assessed sense of direction, i.e., the ability to locate and orient themselves in an environment (Kozlowski & Bryant, 1977). Other personal visuo-spatial inclinations also concern an individual's attitudes to and feelings about visiting places, like pleasure in exploring, as well as spatial anxiety (i.e. worrying about getting lost), which respectively reflect positive and negative inclinations to approaching the environment (De Beni et al., 2014; Lawton, 1994).

Overall, research in the spatial cognition domain has advanced our understanding of the variety of processing resources and abilities involved in navigation and environment learning (e.g., Wolbers & Hegarty, 2010). Individuals' visuo-spatial factors, in terms of objective visuo-spatial abilities and self-assessed visuo-spatial inclinations, have been shown to play a crucial role in supporting environment learning, thus allowing individuals to get to places, as well as locate objects and interact with them and memorize their position (e.g., Hegarty et al., 2006; Uttal et al., 2013), which represent fundamental activities for individuals' everyday functioning and their purpose of living autonomously. It is, thus, of interest to consider how spatial abilities, i.e., spatial learning skills as well as individuals' visuo-spatial factors, change with aging, as discussed in the next paragraph.

1.2 Environment learning and individuals' visuo-spatial factors: the role of age.

As underlined by a growing number of studies, increasing age is associated with a decline in environment learning (e.g., Iachini, Iavarone & Ruotolo, 2009; Klencken, Deprés & Dofour, 2012; Moffat, 2009): after navigating a new path, older adults encounter greater difficulties than young adults in recalling, for example, a succession of landmarks encountered along the way (e.g., Meneghetti, Borella, Carbone, Martinelli & De Beni, 2016a), repeating the route learned (e.g., Barrash, 1994; Chusman, Stein & Duffy, 2008; Wilkins, Jones, Korol, Gold & Manning, 1997) or locating landmarks on a map (e.g., Meneghetti et al., 2016a; Muffato, Meneghetti & De Beni; 2016; 2018; Yamamoto & DeGirolamo, 2012; see Colombo et al., 2017; Lester et al., 2017 for reviews).

At the same time, visuo-spatial abilities and inclinations have shown age-related changes following different trajectories across the adult life span. Self-assessed visuo-spatial inclinations do not seem sensitive to aging and are thought to represent fairly stable individual characteristics (e.g., Borella, Meneghetti, Ronconi, & De Beni, 2014). Objective visuo-spatial abilities, in contrast, decline with age (e.g., Borella et al., 2014; Mammarella, Borella, Pastore, & Pazzaglia, 2013). In particular, within the rotation ability, the ability to mentally rotate objects (as measured by means of the Mental Rotations Test; Vandenberg & Kuse, 1978) seems to deteriorate with a linear trend from youth to old age, while perspective-taking abilities (as measured with the Object Perspective Test; Kozhevnikov & Hegarty, 2001) show non-linear age-related effects, deteriorating more markedly from the age of about fifty onwards (Borella et al., 2014; see also Kaltner & Jansen, 2016). VSWM is not only sensitive to age-related decline (e.g., Borella, Carretti, & De Beni, 2008; Craik & Salthouse, 2011; Lichtenberger & Kaufman, 2009; Mammarella et al., 2013), but also among the main factors underlying age-related effects on high-order visuo-spatial abilities (e.g., Borella et al., 2014; Salthouse, Mitchell, Skovronek, & Babcock, 1989; see also Kantler & Jansen, 2016). Previous studies indeed found that VSWM mediates the age-related impairments seen in high-order visuo-spatial skills (e.g., Meneghetti et al., 2014; Salthouse et al., 1989), and rotation ability in particular (e.g., Briggs, Raz & Marks, 1999; Borella et al., 2014; Kantler & Jansen, 2016; Raz, Briggs, Marks & Acker 1999; see Klencklen et al, 2012 for a review). Despite their age-related changes, visuo-spatial abilities and inclinations have been shown to play a role in explaining the age-related differences between young and older adults' environment learning skills (e.g., Meneghetti et al., 2016; Muffato et al., 2016; 2018; 2019) or, more broadly, their ability to orient themselves in the environment (Meneghetti, Borella, Pastore, & De Beni, 2014).

1.3 Age-related differences between young and older adults' visuo-spatial abilities and inclinations: open issues.

Given the role of individuals' visuo-spatial factors in supporting environment learning both in young and older adults, it is of interest to further explore the age-related differences between young and older adults' visuo-spatial abilities and inclinations in order to shed more light on some issues that still need to be further elucidated.

One issue regards the role of other individual characteristics - apart from age - in influencing individuals' visuo-spatial factors. So far, research has focused, for example, on cognitive mechanisms (e.g., processing speed) or gender differences as potential moderators of age-effects on visuo-spatial abilities and inclinations (e.g., Hegarty & Waller, 2005; Techetin, Vojer, & Vojer, 2014). There is now growing interest in understanding whether other individual characteristics may influence them, and one potential factor could be personality.

Another issue that deserves further investigation lies in the way in which visuo-spatial abilities are measured and assessed both in experimental and clinical settings. In particular, the assessment of a core cognitive mechanism like VSWM is an important aspect. Indeed, VSWM, thanks to its role in the encoding and processing of visuo-spatial information, is essential in supporting individuals' visuo-spatial abilities, such as rotation (e.g., Borella et al., 2014; Hegarty & Waller, 2005; Meneghetti et al., 2014), and, in turn, sustains environment learning both in young and older adults (e.g., Meneghetti et al., 2014; see Klencklen et al., 2012; Lester, et al., 2017; Moffat, 2009; Techetin et al., 2014 for reviews).

The next paragraphs offer an overview of the literature on these two issues.

1.3.1 Individual differences in visuo-spatial abilities and inclinations: the role of personality.

Personality traits refer to an individual's consistent pattern of thoughts, feeling and actions (McCrae & Costa, 1999). According to the dominant theoretical framework of the Big Five model (Goldberg, 1993), personality can be divided into five major traits – Energy (or Extraversion), Conscientiousness, Emotional Stability, Agreeableness, and Openness. Each of these traits is also defined by narrower characteristics, namely facets. A significant body of evidence shows that personality is related to relevant life outcomes (e.g., academic and occupational achievement, quality of interpersonal relationships, physical and psychological health, and longevity) (Ozer & Benet-Martinez, 2006; Roberts, Kuncel, Shiner, Caspi, & Goldberg, 2007), as well as to general intellectual abilities (i.e., crystallized intelligence, fluency and knowledge) (Ackerman & Heggestad, 1997; Ackerman, 2018).

Although personality traits are generally conceived as fairly stable individual characteristics (Costa & McCrae, 1992), there is evidence of them changing over the life span: Extraversion tends to decrease, Openness peaks in adolescence and only declines in later adulthood (in people over 75 years old, the so-called ‘fourth age’; Costa, McCrae, & Löckenhoff, 2018; Roberts, Walton, & Viechtbauer, 2006), while Conscientiousness, Emotional Stability, and Agreeableness increase over time. Studies involving healthy older adults have also demonstrated an association between personality traits (measured using the Big Five model) and cognition, either in terms of both general intellectual abilities or global cognitive functioning, or in certain specific cognitive domains, such as verbal cognitive ability, memory functioning (e.g., Curtis et al., 2015; Luchetti, Terracciano, Stephan, & Sutin, 2015; Waris, Soveri, Lukasik, Lehtonen, & Laine, 2018) and fluid intelligence -this latter assessed using reasoning and spatial visualization tasks (Baker & Bischel, 2006; Chapman et al., 2017; Graham & Lachman 2012; 2014; Schaie, Willis, & Caskie, 2004; Sharp, Reynolds, Pedersen, & Gatz, 2010; Soubelet & Salthouse, 2010; 2011). The associations between personality and cognition are generally modest in older adults (e.g., Curtis et al., 2015), and the most consistent findings point to higher Openness and Conscientiousness, and lower Neuroticism correlating positively with a better cognitive functioning, as in adulthood, and with a slower age-related cognitive decline (e.g., Curtis et al., 2015; Luchetti et al., 2015). In fact, older adults scoring higher for Openness and Conscientiousness, for instance, seem more likely to engage in cognitively stimulating activities (e.g., reading newspapers, learning to use a computer) that have been found to positively affect cognitive functioning, and they are more likely to adopt a healthy lifestyle that protects against the effects of cognitive aging (Curtis et al., 2015). In contrast, Neuroticism (i.e., lower Emotional Stability) has been indicated as a risk factor for cognitive decline: individuals scoring higher for Neuroticism seem less able to control their own negative emotional reactions (such as anger or anxiety), and are therefore more exposed to the detrimental effects of anxiety and stress, which can negatively affect cognitive performance (Curtis et al, 2015; Luchetti et al., 2015). We still know little about the relationship between personality and visuo-spatial abilities and inclinations, however.

The few studies conducted on young adult indicated that personality traits are only weakly related to objective visuo-spatial abilities (Condon et al., 2015; Pazzaglia, Meneghetti, & Ronconi, 2017; Waris et al., 2018), as measured with paper-and-pencil tasks [like the Mental Rotations Test (Vandenberg & Kuse, 1978)] (Condon et al., 2015; Pazzaglia et al., 2017), or using classic VSWM laboratory-based measures [like the Corsi Blocks Task (Corsi, 1972), or the Pathways Span task (Mammarella, Toso, Pazzaglia, & Cornoldi, 2008)], or assessed using verbal, visuo-spatial and updating tasks (see Waris et al., 2018). As for aging studies, to our knowledge, the association between personality traits and visuo-spatial abilities has only been investigated by Schaie, Willis and Caskie (2004). They found that higher Openness and lower Agreeableness predicted a better spatial rotation performance in individuals from 22 to 84 years old, though accounting for a very small part of the variance (6%).

Concerning self-assessed visuo-spatial inclinations, Condon et al. (2015) found that self-assessed Sense of Direction (i.e., people’s estimation of their ability to orient themselves in the environment) was positively related with scores for Extraversion, Intellect/Openness, Conscientiousness, and Emotional stability, but not with Agreeableness. Pazzaglia et al. (2017) recently extended the analysis to positive and negative self-reported inclinations regarding environment-related tasks as pleasure in exploring and spatial anxiety. The results obtained by Pazzaglia et al. (2017) showed that pleasure in exploring and spatial anxiety were both (inversely) related to personality traits and facets, but slightly differently. In particular, pleasure in exploring correlated positively with Extraversion (the Dynamism and Dominance facets), Openness (the Openness to Experience facet), and Conscientiousness (the Perseverance facet), while spatial anxiety correlated negatively with Extraversion (Dynamism), Openness (Openness to Experience), Emotional stability (Emotion Control), and Conscientiousness (Scrupulousness).

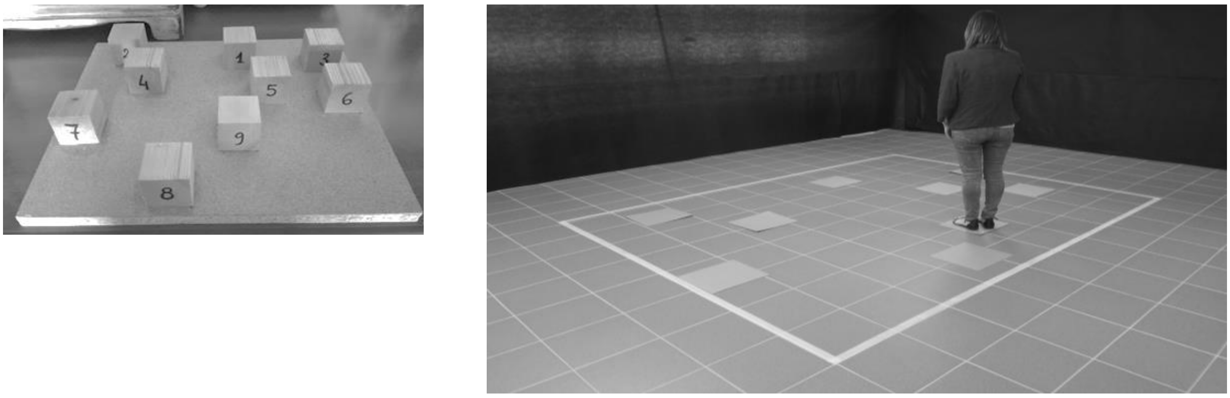
In short, while the association found between personality and objective visuo-spatial abilities - addressed in a few studies (in young adults: Condon et al., 2015; Pazzaglia et al., 2017; Waris et al., 2018; in older adults: Schaie et al., 2004) - has proved weak, a moderate association between personality and self-assessed visuo-spatial inclinations has emerged, though only in young adults (Condon et al., 2015; Pazzaglia et al., 2017). Such a relationship between personality and individuals' visuo-spatial factors has yet to be clarified, and thus merits further investigation.

1.3.2 Assessing objective visuo-spatial abilities: classic tasks and a new measure of VSWM.

Visuo-spatial abilities are usually assessed, both in young and older adults, using paper-and-pencil or computerized tasks requiring visuo-spatial perception, mental rotation or memory of shapes and objects (e.g., Hegarty et al., 2006). The visuo-spatial tasks that are usually administered to assess VSWM also involve handling visuo-spatial stimuli presented on boards, sheets of paper, or computer screens. A well-established and often-used VSWM task is the backward Corsi Blocks Task (CBT; Corsi, 1972), which involves recalling increasingly long sequences of blocks placed at random on a wooden board, and mentally rearranging information to reproduce the sequences in reverse order (see Brown, 2016; see also Berch, Kritorian & Huha, 1998; Donolato, Giofrè & Mammarella, 2017, for a review of the literature).

An extended version of the CBT was recently developed, called the Walking Corsi Test (WalCT) (see Piccardi et al., 2008; 2013; 2019). In this task, nine squares (30 x 30 cm) are placed within a 2.5 × 3.0 m rectangle drawn on the floor so as to reproduce the scaled positions and relative spatial layout of the CBT (Corsi, 1972). The WalCT attempts to assess VSWM resources for storing and handling visuo-spatial information, requiring whole-body movement, and a consequently greater interaction with a real-world environment than classic VSWM tasks (see Piccardi et al., 2008; 2010; 2011; 2013; 2014; 2019; see also Mitolo et al., 2015; Klencklen, Lavenex, Bradner & Lavenex, 2017 for a similar setting): participants are asked to recall increasingly-long series of spatial locations, repeating them either in their original order of presentation (in the forward version: e.g., Piccardi et al., 2008; 2010; 2011; 2013; 2014; 2019; Palmiero, Nori, Rogolino, D'Amico, & Piccardi, 2015) or in reverse (in its backward version: Piccardi et al., 2019; see also Palmiero et al., 2015) while moving around in this larger -vista space- controlled setting (see Piccardi et al., 2019).

Figure 1.1. *The Corsi Blocks Task (Corsi, 1972) and the Walking Corsi Test (Piccardi et al., 2019) apparatus.*



The two studies conducted to date that involved older adults using the WalCT only adopted its forward version (Piccardi et al., 2011; 2013). Both studies showed that this task is sensitive to age, with performance beginning to decline by 47 years of age (Piccardi et al., 2013), and young adults faring better than older people (Piccardi et al., 2011). Bianchini et al. (2014) also found patients with early-stage Alzheimer's disease (AD) selectively impaired in the forward WalCT with respect to the classic forward CBT, and this suggests that the assessment of spatial memory with a task like the WalCT, that entails participants moving around a controlled setting, might be particularly useful for clinical purposes in the aging field.

No studies as yet have administered older adults the backward version of the WalCT (Piccardi et al., 2019), however, which might be considered more demanding -in terms of the processing resources and attentional control required- than its forward one (see Brown, 2016), and thus be configured as a complex VSWM span task. It should be noted that the relationship between the backward WalCT and other classic VSWM measures has yet to be determined. Furthermore, its relationship with other well-proven visuo-spatial measures assessing high-order visuo-spatial skills, such as rotation, is worth investigating. It is indeed of interest to ascertain the contribution of the backward WalCT in explaining age-related effects on rotation ability (e.g., Briggs et al., 1999; Borella et al., 2014; Kantler & Jansen, 2016; Raz et al., 1999; see Klencklen et al., 2012 for a review).

1.4 Improving spatial abilities in aging: what does the literature suggest?

Given the detrimental costs associated with cognitive aging, research has now attempted to identify effective ways to delay age-related cognitive decline and prevent pathological aging, in order to promote active aging and support older adults' autonomy and quality of life. Efforts to address this issue include cognitive procedures, whose benefits in supporting older adults' cognitive functioning have been the focus of growing research in the aging field (see Herzog, Kramer, Wilson, & Lindemberger, 2008; Mewborn, Lindberg, & Miller, 2017; Reichman, Fiocco, & Rose, 2010). In this vein, different approaches are reported in the literature, and two major categories can be identified: on the one hand, there are procedures which focus on teaching strategies, such as mnemonics, for improving older adults' cognitive functioning (e.g., Lustig, Shah, Seidler, & Reuter-Lorenz, 2009; Verghaeghen, Marcoen, & Goossens, 1992); on the other hand, there are the so-called process-based training, which focus on training, without teaching any strategy, central cognitive mechanisms (e.g., working memory, processing speed, executive functions), with the purpose of producing more substantial effects in cognitive abilities that depend upon such domain-general processes and that share common neural substrates (e.g., Morrison & Chein, 2011). Notably, working memory (WM) training has emerged as a proxy for improving cognitive functioning in aging (e.g., Neely & Nyberg, 2015; Mewborn et al., 2017).

Since environment learning is among those abilities sensitive to age-related decline and is fundamental in preserving older adults' autonomy and independent mobility (e.g., Yen & Anderson, 2012), there is an increasing need to understand how older adults' route learning skills might be supported. Further, given the key role played by VSWM in influencing performance in visuo-spatial tasks, it would be of interest to further understand whether targeting VSWM through effective cognitive training benefits visuo-spatial abilities.

It should be noted that to date, surprisingly, there is a paucity of studies exploring the issue of supporting and improving older adults' spatial abilities. Taking into account the two abovementioned approaches, some suggestions from the literature are presented in the next paragraphs to move towards the adoption of new effective modalities and procedures to support/improve spatial learning abilities as well as visuo-spatial skills in older adults.

1.4.1 Supporting route learning in older adults: the role of imagery strategy.

It is now well-proven that visuo-spatial tasks performance is susceptible to strategy use (see Gluck & Fitting, 2003 for a review). In particular, strategies based on imagery, i.e., based on forming simple or more elaborate visual images of the information to be encoded, processed/manipulated and retained in the mind's eye, have been shown to be the most effective to solve visuo-spatial tasks (Gluck & Fitting, 200; see also Bilge & Taylor, 2017).

To date, the benefit of practicing and using imagery strategy, in young adults at least, has been explored to support/improve both rotation ability and spatial (route) learning. However, few studies have addressed this issue.

As for rotation ability, Meneghetti and colleagues (2017), for instance, tested the efficacy of instructing participants to use imagery strategy in combination with practice on mental rotation tasks (i.e., the 3D same/different mental rotation task adapted from Shepard & Metzler [1971]). Participants were taught how to imagine having to rotate the whole stimuli (i.e., 3D figures composed by cubes) to perform rotation tasks - which has been shown to be the most effective strategy to support mental rotation performance (Bilge & Taylor, 2017), and were allowed to gain experience on the use of imagery strategy thanks to example activities, before starting the actual practice with rotation tasks. The authors found that using imagery strategy (here based on imagining whole stimulus rotation) contributed considerably to the efficacy of rotation training, prompting training benefits which were also generalized, in the long-term, to untrained visuo-spatial abilities, such as perspective taking, and to fluid intelligence.

Concerning spatial (route) learning, some studies have shown that instructing (De Beni & Moè, 2003; Gyselinck, Meneghetti, De Beni & Pazzaglia, 2009) or training (Gyselinck, De Beni, Pazzaglia, Meneghetti & Mondolini, 2007; Meneghetti, De Beni, Gyselinck & Pazzaglia, 2013) young adults to use imagery strategy, i.e., to mentally visualize the path and the location of landmarks, while learning a route (from spatial descriptions) improve their performance in spatial recall tasks, such as naming the landmarks and their locations (De Beni & Moè, 2003; Gyselinck et al., 2009), or drawing a map of the environment (Gyselinck et al., 2009; Meneghetti et al., 2013). Imagery strategy use (here based on forming images of global configurations when acquiring environmental information) does indeed seem to favor the construction of better spatial representations of an environment, thereby facilitating young adults' spatial recall (e.g., Gyselinck et al., 2007; 2009; Meneghetti et al., 2013).

The results from these abovementioned studies involving young adults begin to address the issue as to whether instructing or training older adults to use imagery strategy might be an effective way to support their spatial abilities. The beneficial effect of imagery strategy use in aging has already been demonstrated, especially in relation to episodic memory performance (e.g., Craik & Rose, 2012; Verhaeghen et al., 1992) and, in a broad sense, in the verbal domain (see Ariel & Moffat, 2018; Craik & Rose, 2012): although it is well-documented that older adults are less likely than young adults to spontaneously use deep internal strategies like imagery to approach various memory tasks (e.g., Craik & Rose, 2012; Lemaire, 2010; 2015; Luo & Craik, 2008), they have nonetheless been shown to benefit from being advised or taught to use imagery strategy, to promote the deep encoding and subsequent recall of information essential to good memory performance (e.g., Craik & Rose, 2012; Gross et al., 2012; Herzog, Kramer, Wilson & Lindenberger, 2008; Verhaeghen, Marcoen & Goossens, 1992).

Concerning visuo-spatial tasks, in the light of the promising findings gained with young adults, Meneghetti and colleagues (2018) used the same training approach, i.e., imagery strategy instructions in combination with practice on rotation tasks, here involving a sample of healthy older adults. Before starting the practice with mental rotation tasks (i.e., the 3D same/different mental rotation task adapted from Shepard & Metzler [1971] and the Tetris game), older participants were taught how to imagine having to rotate whole visuo-spatial stimuli (i.e., the 3D figures composed by cubes in the 3D same/different mental rotation task, and the 2D Tetraminos composed by colored cubes for the Tetris game) to perform the rotation tasks, and experience the use of imagery strategy thanks to example activities, which also involved the manipulation of concrete objects (i.e., wooden models of the stimuli to be mentally rotated) to make the activities more meaningful, and thus the instructions more effective. Results confirmed that even in older adults imagery strategy instructions (here using both the manipulation of concrete objects and imagery) combined with practicing with rotation tasks prompted benefits not only in the rotation ability actually trained but also, especially in the long-term, in other related visuo-spatial skills, such as perspective taking and fluid intelligence.

So far, however, the benefit of practicing and using an imagery strategy to perform visuo-spatial tasks in older adults has been explored only in relation to rotation ability, and the abovementioned study is the only one in the aging field. Furthermore, no studies have yet ascertained the beneficial role of practicing and using imagery strategy to perform route learning tasks in older adults, an issue that is thus worth investigating.

1.4.2 Targeting VSWM to improve older adults' visuo-spatial skills: towards more interactive and engaging training modalities.

As mentioned above, WM training usually requires older participants to practice - without receiving explicit instructions on the use of strategies - on complex working memory span tasks (i.e., recalling a sequence of stimuli and simultaneously performing another activity), or updating tasks (i.e., holding specific content in memory, updating information to be remembered and dropping information that is no longer needed) presented in visual or auditory modalities using computer-based or tablet-based procedures (see Teixeira-Santos et al., 2019). The success of WM training lies in the fact that training WM gives rise to changes in the way in which individuals process information, enabling them to make more flexible use of their own resources (e.g. Bürki, Ludwig, Chicherio, & de Ribaupierre, 2014; Zinke, Zeintl, Eschen, Hertzog, & Kliegel, 2012). Thus, training WM, a mechanism sensitive to age-related decline and involved in various complex cognitive processes that are also related to everyday life abilities (e.g., Park et al., 2002), has the potential not only to provide benefits on the trained tasks (specific training gains) but also to promote transfer effects to untrained tasks that share common cognitive processes with the trained ones (see the taxonomy proposed by Noack, Lövdén, Schmiedek, & Lindenberger, 2009).

The debate on the strengths and limitations of WM training efficacy to sustain/improve older adults' cognitive functioning has been addressed by recent review and meta-analyses (see Karbach & Verhaeghen, 2014; Lampit, Hallock, & Valenxuela, 2014; Teixeira-Santos et al., 2019). So far, there is evidence for WM training to provide specific training gains (in WM tasks similar to the ones trained), and near transfer effects are commonly, but not always, observed (e.g., Karbach & Verhaeghen, 2014; Teixeira-Santos et al., 2019). Benefits in terms of far transfer effects still remain controversial (see Constantinidis & Klingberg, 2016; Karbach & Verhaeghen, 2014; Lampit et al., 2014; Melby-Lerväg & Hulme, 2016, 2013; Morrison & Chein, 2011; Schwaighofer, Fischer, & Bühner, 2015; von Bastian & Oberauer, 2013).

It is worth stressing that, to date, the majority of studies administering WM training to healthy older adults included training tasks with verbal stimuli or were cross-modal training programs (i.e., targeting both verbal and visuo-spatial subcomponents of working memory; see Teixeira-Santos et al., 2019), while only a few studies exclusively used training tasks with visual or visuo-spatial stimuli (see Table 1.1 for details). It is also worth noticing that such VSWM training promoted specific training gains, but they did not result in robust and consistent transfer effects in the outcome measures considered (see Table 1.1). Among other factors, one possible explanation for such a pattern of findings from VSWM training is thought to lie in the training modalities adopted (e.g., Borella et al., 2014). Such training programs require participants to cope with task demands that are less familiar, especially for older adults, and unrelated to their prior knowledge (e.g., Vecchi & Cornoldi, 1999), thus possibly being more complex to understand. Furthermore, they mostly entail the processing of meaningless stimuli (e.g., remembering the position of shapes or pictures in a matrix). The nature of the demands of the tasks as well as of the stimuli presented might prevent older adults from seeing the training activities as challenging and engaging, limiting, in turn, their motivation and interest towards the training program, which are among those factors that are crucial for promoting training benefits, especially in terms of transfer effects (e.g., Katz, Jones, Shah, Buschkuehl, & Jaeggi, 2016 for a review).

There is, therefore, a need to further investigate the feasibility and the efficacy of using procedures to train VSWM which attempt to be more engaging for older adults, also taking into account that individuals engage visuo-spatial skills in everyday life performing activities that require them to interact to a great extent with the real-world environment. Any transfer effects to other visuo-spatial skills in which VSWM is involved, such as rotation ability, deserve further investigation too. Rotation ability has never been included as an outcome measure for the assessment of WM training benefits in aging studies.

Table 1.1. *Summary of WM training programs for older adults targeting visual or VSWM only.*

Study	Sample characteristics	Training program & Control condition	Timing & Procedure	Outcome measures	Short-term benefits	Long-term benefits
Jaeggi et al., (2019)	183 OA (age range: 65 years old and older)	- *Training groups* Home-based tablet visual n-back training: stimuli were pictures of everyday common objects - *Control groups:* tablet-based general knowledge task (i.e., vocabulary questions)	- *Number and duration of the training sessions* 20 sessions, each lasting about 15 min, to be completed in three conditions: twice per day, once per day or once every-other-day - *Training procedure* Adaptive	- WM: spatial n-back, Sternberg, Symmetry Span - Inhibition: D2, spatial n-back false alarms, visual-long-term memory intrusions - Long-term memory: visual-long-term memory, metamemory, CEDAR - Processing speed: letter and pattern comparisons	Specific training gains and transfer effects within the targeted domain (i.e., to another WM measure and inhibition/interferences indices) No effects of the variation of the training schedule	*3 months after the training:* Specific training gains and transfer effects within the targeted domain (i.e., to another WM measure and inhibition/interferences indices)
Pergher et al. (2018)	18 YA (age range: 21-34 years) 28 OA (age range: 55-69 years)	- *Training groups* Lab-based computerized visual n-back training: stimuli were pictures of everyday common objects - *Control groups:* Passive	- *Number and duration of the training sessions* 10 sessions, 3 times per week (lasting 30 min each) - *Training procedure* Increasing load difficulty (from 1 to 3 back) within each training session	-Visual WM: n-back (non-adaptive) -Attention: Test of Variables of Attention - Visuo-spatial short-term memory: Corsi Blocks Task - Reasoning: RAVEN	In OA: Specific training gains and transfer effects to attention and reasoning measures In YA: Specific training gains and transfer effects to reasoning measures Greater improvement for OA than YA	NA
Guye & Von Bastian (2017)	142 OA (age range: 65-80 years)	-*Training group* Home-based computerized training: participants practiced with a complex span task, a binding task and an updating task with figural-spatial stimuli presented in 4x4 grids. -*Control group:* Visual search training (adaptive)	-*Number and duration of the training sessions* 25 sessions, 5 times per week (each lasting about 40 min) -*Training procedure* Adaptive across training sessions	-VSWM: Complex span (Brown-Peterson) Binding Updating -Executive functions: Shifting Inhibition (Flanker, Stroop, Simon) -reasoning: RAPM	Specific training gains in the trained tasks but any transfer effects to other VSWM measures; absence of transfer effects to executive functions and reasoning measures	NA
Cantarella et al. (2017)	Study 1 35 OA (age range: 65-75 years)	- *Training group* Lab-based computerized VSWM training: participants practiced with variants of a	- *Number and duration of the training sessions*	- WM: Matrix task CWMS	Specific training gains only in both studies	*8 months after the training:* Specific training gains only in both studies

	Study 2 35 OA (age range: 65-75 years)	complex VSWM span task with figural stimuli (images of neutral valence in Study 1, images with positive valence in Study 2) presented in 4x4 grids. - *Control group:* Filling in questionnaires	3 sessions, within a two-week schedule, each lasting about 45 min - *Training procedure* Hybrid: adaptive procedure combined with variations of tasks' demands and complexity	- Visuo-spatial short-term memory: Corsi Blocks test - Processing speed: Pattern comparison - Inhibition: Stroop color task - Reasoning: Cattell test		
Borella et al. (2014)	40 YA (age range: 18-35 years) 40 OA (age range: 65-75 years)	- *Training group* Lab-based computerized VSWM training: participants practiced with variants of a complex VSWM span task with figural (dots) stimuli presented in 4x4 grids. - *Control group:* Filling in questionnaires	- *Number and duration of the training sessions* 3 sessions, within a two-week schedule, each lasting about 45 min - *Training procedure* Hybrid: adaptive procedure combined with variations of tasks' demands and complexity	- WM: Matrix task CWMS Visuo-spatial memory: Corsi Blocks task (forward and backward) -Processing speed: Pattern comparison -Inhibition: Stroop color task -Reasoning: Cattell test	In OA: Specific training gains in WM measures only In YA: training benefits in WM measures and transfer effects to measures of visuo-spatial memory and processing speed	*8 months after the training* In OA: Specific training gains in WM measures only In YA: specific training gains in WM measures only
Buschkuehl et al. (2008)	39 OA (mean age of 80)	- *Training group* Lab-based computerized visual WM training: participants practiced with WM tasks entailing to process and recall sequences of colored squares or pictures of animals - *Control group:* Physical activity	- *Number and duration of the training sessions* 2 sessions per week, each lasting about 45 min, over a period of 12 weeks - *Training procedure* Adaptive across training sessions	-Visual WM: trained tasks -Short-term memory: Digit span task, block span task -Episodic memory: Verbal free recall, spatial free recall	Specific training gains but no transfer effects	*1 year after the training* Training benefits were not maintained
Li et al. (2008)	46 YA (age range: 20-30 years) 41 OA (age range: 70-80 years)	- *Training group* Spatial n-back training: stimuli were black dots presented in 3 x 3 grids - *Control group:* Passive	- *Number and duration of the training sessions* 45 daily sessions, each lasting about 15 min - *Training procedure* Non adaptive	- WM: trained n-back task, numerical n-back task, operation span task, rotation span task - Processing speed: simple decision speed tasks	Both in YA and OA comparable training gains in the trained tasks and in n-back tasks similar to the one trained but no transfer effects to complex span tasks and processing speed	*3 months after the training* Specific training gains, which were maintained to a larger extent in YA than in OA

Note. YA: young adults; OA: older adults; WM: working memory; VSWM: visuo-spatial working memory; CEDAR = Characterization of the Elderly on Daily Activities in the Real-World; RAPM: Raven Advanced Progressive Matrices; NA: not assessed.

2. Study 1: Do personality traits and facets influence performance on visuo-spatial tasks and self-reported visuo-spatial inclinations in young and older adults?

2.1 Rationale and aims of the study[1]

Personality traits, i.e., an individual's consistent pattern of thoughts, feeling and actions (McCrae & Costa, 1999), relates to relevant life outcomes (e.g., academic and occupational achievement, quality of interpersonal relationships, physical and psychological health, and longevity) (Ozer & Benet-Martinez, 2006; Roberts, Kuncel, Shiner, Caspi, & Goldberg, 2007). At the same time, it has been also suggested to influence individuals' cognitive performance (i.e., crystallized intelligence, fluency and knowledge) (Ackerman & Heggestad, 1997; Ackerman, 2018).

Studies involving healthy older adults have also demonstrated an association between personality traits and global cognitive functioning, or certain specific cognitive domains, such as verbal cognitive ability, memory functioning (e.g., Curtis et al., 2015; Luchetti, Terracciano, Stephan, & Sutin, 2015; Waris, Soveri, Lukasik, Lehtonen, & Laine, 2018) and fluid intelligence -as measured with reasoning and spatial visualization tasks (Baker & Bischel, 2006; Chapman et al., 2017; Graham & Lachman 2012; 2014; Schaie, Willis, & Caskie, 2004; Sharp, Reynolds, Pedersen, & Gatz, 2010; Soubelet & Salthouse, 2010; 2011). The most consistent findings point to higher Openness and Conscientiousness, and lower Neuroticism correlating positively with a better cognitive functioning, and with a slower age-related cognitive decline (e.g., Curtis et al., 2015; Luchetti et al., 2015).

We still know little about the relationship between personality and individuals' visuo-spatial factors, in terms of their objective visuo-spatial abilities and their self-assessed visuo-spatial inclinations (e.g., Hegarty, Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006), known to be involved in several everyday life activities crucial for the mastery of the environment, such as

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[1] Study 1 has been described in Carbone, Meneghetti, & Borella (2019).

spatial orientation and route learning (e.g., Meneghetti et al., 2014; see Klencklen et al., 2012; Lester, Moffat, Wiener, Barnes, & Wolbers, 2017; Moffat, 2009, Techetin, Vojer & Vojer, 2014 for reviews), however. While the association found between personality and objective visuo-spatial abilities - addressed in a few studies (in young adults: Condon et al., 2015; Pazzaglia et al., 2017; Waris et al., 2018; in older adults: Schaie et al., 2004) - has proved weak, a moderate association between personality and self-assessed visuo-spatial inclinations has emerged, though only in young adults (Condon et al., 2015; Pazzaglia et al., 2017). Such a relationship between personality and individuals' visuo-spatial factors has yet to be clarified, especially in aging.

Study 1 thus aimed to newly investigate whether, and to what extent, young and older adults' personality dispositions are associated with their objective visuo-spatial abilities and self-assessed visuo-spatial inclinations.

Using the Big Five model (Goldber, 1993), we considered the five major personality traits, i.e., Energy (or Extraversion), Conscientiousness, Emotional Stability, Agreeableness, and Openness- and their narrower facets, in an effort to better conceptualize the association between personality and objective visuo-spatial abilities and inclinations (Curtis et al., 2015). For the objective visuo-spatial abilities, we focused on rotation ability and visuo-spatial working memory (VSWM). For the former, we administered two well-established tasks: the short Mental Rotations Test (De Beni, Meneghetti, Fiore, Gava & Borella, 2014; adapted from Vandenberg & Kuse, 1978); and the short Object Perspective Test (De Beni et al., 2014; adapted from Kozhevnikov & Hegarty, 2001). To assess VSWM, we used the backward Corsi Blocks Task (Corsi, 1972), the Pathways Span Task (adapted from Mammarella, Pazzaglia & Cornoldi, 2008; Cornoldi et al., 1999), and the Jigsaw Puzzle test (De Beni, Borella, Carretti, Marigo, & Nava, 2008; adapted from Richardson & Vecchi, 2002). As for the self-assessed visuo-spatial inclinations, we focused on positive and negative attitudes to environment-related tasks, i.e. pleasure in exploring places and spatial anxiety, measured with measured with the Attitude to Orientation Task (De Beni et al., 2014; see Muffato, Toffalini, Meneghetti, Carbone & De Beni, 2017), and the Spatial Anxiety scales (De Beni et al., 2014; adapted from Lawton, 1994), respectively.

Since objective visuo-spatial abilities are known to be sensitive to the effects of aging (Borella et al., 2014; Mammarella et al., 2013), whereas self-assessed visuo-spatial inclinations have been found fairly stable over time (Borella et al., 2014; De Beni et al., 2014), we expected to confirm the impairments in older adults in objective visuo-spatial tasks performance, but not in self-assessed visuo-spatial inclinations (Borella et al., 2014; De Beni et al., 2014; Mammarella et al., 2013).

Different patterns of associations might then be expected between personality traits (and facets) and objective visuo-spatial abilities on one hand, and self-assessed visuo-spatial inclinations on the other hand. While the association found between personality and objective visuo-spatial abilities - addressed in a few studies (in young adults: Condon et al., 2015; Pazzaglia et al., 2017; Waris et al., 2018; ; in older adults: Schaie et al., 2004) - has proved weak, a moderate association between personality and self-assessed visuo-spatial inclinations has emerged, though only in young adults [29,30]. Therefore, for objective visuo-spatial abilities we would expect to find, in line with previous studies in young (e.g., Condon et al., 2015) and older adults (Schaie et al., 2004; see also Bacher & Bischel, 2006; Chapman et al., 2017; Graham & Lachman, 2014; Sharp et al., 2010; Soubelet & Salthouse, 2010; 2011), some (albeit modest) associations between most major personality traits and performance on visuo-spatial tasks. For the self-assessed visuo-spatial inclinations, not impaired by increasing age (Borella et al., 2014; De Beni et al., 2014), on the other hand, we would expect to find stronger associations with most personality traits, as previously suggested, in young adults at least (Condon et al., 2015; Pazzaglia et al., 2018).

As for personality facets, we might expect them to mirror the pattern of associations found between major personality traits and objective visuo-spatial abilities, on one hand, and self-assessed visuo-spatial inclinations, on the other hand. However, since it has been suggested that these narrower dimensions of personality are not simply interchangeable with the broad traits they are designed to reflect (Costa et al., 2018; Hofstee et al., 1992; McCrae et al., 2015; Mõttus et al., 2017), we might also expect some different patterns of associations with objective visuo-spatial abilities and self-assessed visuo-spatial inclinations to emerge (compared with those seen for major personality traits). Finally, gender was considered in the analyses too, given the well-known role of gender in influencing visuo-spatial abilities and inclinations (e.g., Linn & Petersen, 1985; Hegarty & Waller, 2005; Lawton, 1994).

2.2 Method

2.2.1 Participants

Seventy young adults (age range: 18-34 years; 36 females) and 70 older adults (age range: 65-75 years; 41 females) volunteered for the study. All participants were Italian mother-tongue community dwellers recruited through associations in north-eastern Italy, or by word of mouth. The inclusion criteria were: (i) a good state of physical and mental health, and no history of psychiatric or neurological disorders, ascertained by means of a semi-structured interview (De Beni, Borella, Carretti, Marigo, & Nava, 2008); and, for older adults, (ii) a score in the Mini-Mental State Examination (Folstein, Folstein & McHugh, 1975) above the cut-off of 27. The two age groups did not differ in terms of educational level, $F_{(1,138)}=1.94$; $p=.16$, $d=.23$, or gender distribution ($\chi^2=.72$, $p=.39$). Participants' demographic characteristics are shown in Table 2.1.

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

	Young adults N=70 (36 females)		Older adults N=70 (41 females)	
	M	*SD*	*M*	*SD*
Age	23.51	2.95	68.63	3.29
Education (in years)	12.74	0.65	12.50	1.31

2.2.2 Materials

2.2.2.1 Personality

Big Five Questionnaire-60 (BFQ; Caprara, Schwartz, Capanna, Vecchione, & Barbaranelli, 2006). This is a short version containing the 60 items with the best psychometric properties from the BFQ [44], with good reliability (Cronbach's alpha from .70 for Energy to .85 for Emotional Stability, and from .53 for Cooperativeness to .81 for Emotion Control). Participants had to indicate the extent to which each of the 60 statements described "how they are" as a person on a 5-point scale from 1 (very false for me) to 5 (very true for me). The answers give rise to five domain scales, i.e., Energy (or Extraversion), Agreeableness, Conscientiousness, Emotional Stability, and Openness, and their related facets, which are respectively Dynamism and Dominance, Cooperativeness and Politeness, Scrupulousness and Perseverance, Emotion Control and Impulse Control, Openness to Culture and Openness to Experience.

2.2.2.2 Objective visuo-spatial abilities

Rotation ability

Short Mental Rotations Test (sMRT; De Beni et al., 2014, adapted from Vandenberg & Kuse, 1978). This task involves identifying two of four abstract 3D objects that match a target object in a rotated position, and has shown a good reliability (Cronbach's alpha=.81). Participants are shown 10 items to complete in 5 min. The final score (the dependent variable) is the number of correct answers (minimum 0 - maximum 10).

Short Object Perspective Test (sOPT; De Beni et al., 2014, adapted from Kozhevnikov & Hegarty, 2001). This task involves looking at a layout of seven objects and imagining standing alongside one object, facing another, and pointing to a third. The layout remains visible to participants and a circle is used to provide the answer. The task has shown a good reliability (Cronbach's alpha=.80). Participants have to complete 6 items with a time constraint of 5 min. The absolute angle of error is calculated for each item in degrees of difference between the correct angle and the one indicated by participants. The final score (the dependent variable) is the mean error in degrees (range 0°-180°), so higher scores correspond to a worse performance.

Visuo-spatial working memory

Backward Corsi Blocks Task (CBT; Corsi, 1972). In this task, blocks (3 x 3 x 3 cm) are placed at random on a board (30 x 25 cm) and the experimenter taps a sequence of blocks, stopping on each block for 2 sec. Then participants are asked to repeat the same sequence of blocks, but in reverse order. The number of blocks in a sequence gradually increases in length (from 2 to 9 blocks). The task has shown a good reliability (Cronbach's alpha=.94). The final score (the dependent variable) is the number of blocks in the longest sequence correctly recalled (minimum 2 - maximum 9).

Jigsaw Puzzle test (Puzzle; De Beni et al., 2008, adapted from Richardson & Vecchi, 2002). This task consists of 27 drawings of common objects, each broken down into numbered pieces forming a puzzle. The task has shown a good reliability (Cronbach's alpha=.83). Each whole drawing is presented together with a corresponding verbal label for 2 sec, then it is hidden. Participants are given the numbered pieces and asked to complete the puzzle, mentally recomposing the figure by indicating where the corresponding pieces should go on a blank matrix, without actually moving them (time constraint for each figure: 90 sec). The complexity of the task varies, depending on the number of pieces forming a given figure (from 2 to 10). The final score (the dependent variable) is the sum of the levels corresponding to the three most difficult puzzles correctly completed.

Pathways Span Task (PST; adapted from Mammarella et al., 2008, Cornoldi et al., 1999). In this computerized version of the original task, which has shown a good reliability (Cronbach's alpha=.85), a matrix with a colored cell in the south-west corner is presented on the screen for 4 sec, and then disappears. Participants are asked to mentally imagine following a path on the matrix, starting from the colored cell, based on directions (i.e., forwards, backwards, left, or right) indicated by sequences of arrows (i.e., up, down, left, right) that appear on the screen one at a time for 2 sec each, with an inter-stimulus interval of 1 sec. Finally, a blank matrix appears and participants are asked to indicate the final position reached. The difficulty of the task varies according to the size of the matrix (from 2 x 2 to 6 x 6 cells) and the length of the path (the number of displacements indicated by the arrows). The final score (the dependent variable) is the sum of the levels corresponding to the three most complex trials completed correctly.

2.2.2.3 Self-assessed visuo-spatial inclinations

Attitudes to Orientation Tasks scale (AtOT; De Beni et al., 2014, see Muffato et al., 2017 for an English translation of the scale). This scale comprises 10 items assessing pleasure (e.g., “I like to find new ways to reach familiar places”; 5 items) and no pleasure (e.g., “When I see a new road, I avoid taking it because I don’t know where it ends”; 5 items) in exploring. It has shown a good reliability (Cronbach’s alpha .83 and .78, respectively). Participants rate each item on a Likert scale from 1 (not at all) to 6 (very much). The score is calculated as the reverse of the rating on the items indicating no pleasure in exploring, so the final score expresses the respondent’s pleasure in exploring (minimum 10 - maximum 60).

Spatial Anxiety scale (SA; De Beni et al., 2014, adapted from Lawton, 1994). This scale comprises 8 items assessing the degree of space-related anxiety experienced in an environment (e.g., “Going to an appointment in an unfamiliar part of the city”), and has shown a good reliability (Cronbach’s alpha=.87). Answers are given on a Likert scale from 1 (not at all) to 6 (very much). The final score is the sum of the ratings for each item (minimum 8 - maximum 48), with higher scores corresponding to greater spatial anxiety.

2.2.3 Procedure

Participants attended two individual sessions of approximately 60 min each, conducted by a trained examiner. At the start of the first session, after signing an informed consent form, all participants completed a general information questionnaire (and the older participants completed the MMSE). Then, the visuo-spatial tasks and the self-assessments were administered in two sets: one included the sMRT, backward CBT, PST and AtOT; the other the Puzzle, sOPT, and BFQ. The order of presentation was the same for all participants within each set, but the order of the sets was counterbalanced between participants and administered at either the first or the second individual session. The SA scale was always presented at the end of the second session to avoid any activation of negative mood.

2.3 Results

The statistical analyses were conducted in two main steps. First, correlations and factor analyses were run to check that the visuo-spatial measures represented two distinct individuals' visuo-spatial factors (i.e., objective visuo-spatial abilities and subjective visuo-spatial inclinations, as conceived here), including the mental rotations tasks (sMRT, sOPT), the VSWM tasks (backward CBT, Puzzle, PST), and the spatial self-assessments (AtOT, SA scales). Principal components factor extraction with Promax rotation was used, applying Kaiser's eigenvalue greater than one rule as well as Horn's (1965) parallel analysis method to derive common underlying factors. Then, Pearson's correlations were run between all the measures of interest. Finally, to elucidate the association between personality and visuo-spatial abilities and inclinations, hierarchical regression analyses were conducted with demographic characteristics, i.e. age and gender (the latter given its influence on visuo-spatial abilities and inclinations), added in Step 1, and the major personality traits, added in Step 2, as predictors of objective visuo-spatial abilities and self-assessed visuo-spatial inclinations (dependent variables), respectively. Then other regression analyses were run, but in this case the narrower facets of personality were added as predictors in Step 2. All the models were checked for outliers (Cook's distance <1).

The raw scores for personality traits and facets were considered in our analyses. Descriptive statistics for the measures of interest are presented in Table 2.2.

Table 2.2. *Means (M) and standard deviations (SD) of the visuo-spatial measures and personality traits and facets by age group.*

	Young adults (N=70)		Older adults (N=70)	
	M	*SD*	*M*	*SD*
Objective visuo-spatial abilities				
Rotation ability:				
short Mental Rotations Test	4.39	2.56	2.33	1.67
short Object Perspective Test	32.69	24.49	52.39	36.56
Visuo-spatial working memory:				
Backward Corsi Blocks Test	5.26	0.94	4.47	0.76
Jigsaw Puzzle test	22.00	4.39	17.91	4.19
Pathways Span Task	24.64	4.82	18.90	5.09
Self-assessed visuo-spatial inclinations				
Attitude to Orientation Tasks scale	34.04	7.27	34.20	8.42
Spatial Anxiety scale	22.29	6.43	21.77	6.58
Personality				
ENERGY	3.16	0.49	3.03	0.44
Dynamism	3.41	0.67	3.29	0.69
Dominance	2.92	0.62	2.78	0.56
CONSCIENTIOUSNESS	3.52	0.57	3.51	0.55
Scrupulousness	3.52	0.64	3.47	0.64
Perseverance	3.52	0.69	3.55	0.61
EMOTIONAL STABILITY	2.90	0.78	3.25	0.54
Emotion Control	2.91	0.90	3.26	0.61
Impulse Control	2.89	0.87	3.24	0.68
AGREEABLENESS	3.35	0.47	3.27	0.52
Cooperativeness	3.52	0.58	3.33	0.58
Politeness	3.19	0.57	3.21	0.57
OPENNESS	3.33	0.51	3.46	0.58
Openness to Culture	3.11	0.67	3.53	0.68
Openness to Experience	3.56	0.68	3.40	0.65

2.3.1 Factor structure of visuo-spatial abilities and inclinations

2.3.1.1 Correlations

Pearson's correlations showed that the rotation ability measures and the VSWM tasks all correlated moderately with one another (see Table 2.2). The AtOT scale correlated moderately and negatively with the SA scale (r=-0.55, p<0.01). No significant correlations emerged between the visuo-spatial tasks as a whole and the two measures of self-assessed visuo-spatial inclinations, apart from a weak correlation between the sMRT and both the AtOT (r=0.20, p<0.05) and the SA (r=-0.27, p<0.01) scales (see Table 2.2).

2.3.1.2 Factor analysis

The Kaiser-Meyer-Olkin measure of sampling adequacy was .73 [above the commonly recommended value of .60 (Hutcheson & Sofroniou, 1999)], and Bartlett's test of sphericity was significant ($\chi 2(21) = 247.10, p < .001$). Both Kaiser's eigenvalue criterion and Horn's parallel analysis confirmed that two factors, which explained 62.28% of the variance in the model (r=.14), should be retained. The two mental rotation and three VSWM measures loaded strongly on the first factor (see Table 2.3), which explained 39.46% of the variance (eigenvalue=2.76), and could be interpreted as expressing objective visuo-spatial abilities. The second factor, which explained 22.80% of the variance (eigenvalue=1.59), and the two spatial self-assessments loaded strongly on it (see Table 2.3), was interpreted as referring to self-assessed visuo-spatial inclinations.

In the light of the results of factor analysis, and considering the moderate-to-large correlations between the objective visuo-spatial abilities, and the large correlation between the two spatial self-assessments, two composite scores were then calculated, one by averaging the *z*-scores from the two rotation ability measures and the three VSWM tasks, the other by averaging the *z*-scores from the two self-assessment scales of visuo-spatial inclinations. These composite scores were used in subsequent analyses as measures of objective visuo-spatial abilities and self-assessed visuo-spatial inclinations, respectively.

Table 2.3. *Correlation matrix and results of factor analysis (Promax rotation method) for measures of objective visuo-spatial abilities and self-assessed visuo-spatial inclinations.*

	1	2	3	4	5	6	Objective visuo-spatial abilities	Self-assessed visuo-spatial inclinations
1. sMRT	-						**.64**	.32
2. sOPT	-0.37**						**-.75**	.06
3. Backward CBT	0.40**	-0.48**					**.75**	-.06
4. Puzzle	0.52**	-0.38**	0.40**				**.73**	.11
5. PST	0.33**	-0.47**	0.42**	0.46**			**.77**	-.20
6. AtOT scale	0.20*	0.04	0.01	0.10	-0.09		-.10	**.88**
7. SA scale	-0.27**	0.14	-0.06	-0.14	-0.01	-0.55**	-.04	**-.84**

Note. *n*=140; sMRT: short Mental Rotations Test; sOPT: short Object Perspective Test; backward CBT: backward Corsi Blocks Task; PST: Pathways Span Task; AtOT: Attitude to Orientation Task scale; SA: Spatial Anxiety scale.

*$p < 0.05$. **$p < 0.01$

Factor loadings higher than .50 (in bold) were used to interpret the factors.

2.3.2 Relation between personality, objective visuo-spatial abilities and self-assessed visuo-spatial inclinations

2.3.2.1 Correlations

Age showed a large negative correlation with objective visuo-spatial abilities, while no significant correlations emerged between age and self-assessed visuo-spatial inclinations (see Table 2.4). Small positive correlations were also found between age and: (i) the Emotional Stability trait (and both its facets, Emotion Control and Impulse Control); (ii) the Openness to Culture facet of the Openness trait.

Gender correlated positively (albeit weakly), in favor of males, with the self-assessed visuo-spatial inclinations, but not with objective visuo-spatial abilities (see Table 2.4).

Although no correlations emerged between objective visuo-spatial abilities and major personality traits, small negative correlations came to light between the objective visuo-spatial abilities and the facets Dynamism, Politeness, and Openness to Culture. Self-assessed visuo-spatial inclinations correlated positively with almost all personality traits and facets (see Table 2.4). In particular, self-assessed visuo-spatial inclinations showed small correlations with: (i) the Agreeableness trait and its Cooperativeness facet; (ii) the Dominance facet of Energy, the Impulse Control facet of Emotional Stability, and (iii) the Openness to Culture facet of Openness. On the other hand, they showed medium correlations with the Conscientiousness trait and its Perseverance and Scrupulousness facets, and with the Emotional Stability trait and its Emotion Control facet.

Table 2.4. *Correlation matrix for all measures of interest.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Age	-																	
2. Gender[a]	-.07																	
3. Objective visuo-spatial abilities	-.59**	.15																
4. Self-assessed visuo-spatial inclinations	.04	.37**	.12															
5. ENERGY	-.11	-.11	-.08	.14														
6. Dynamism	-.07	-.30**	-.17*	.02	.77**													
7. Dominance	-.09	.15	.06	.19*	.68**	.07												
8. CONSCIENTIOUSNESS	-.01	-.01	.08	.40**	.23**	.23**	.10											
9. Scrupulousness	-.03	.04	.11	.31**	.12	.12	.05	.86**										
10. Perseverance	.02	-.05	.03	.38**	.27**	.26**	.12	.86**	.48**									
11. EMOTIONAL STABILITY	.26**	.16*	-.01	.34**	-.06	-.15	.07	.07	.06	.06								
12. Emotion control	.23**	.19*	.04	.41**	.01	-.15	.19*	.06	-.00	.12	.87**							
13. Impulse control	.22**	.10	-.06	.19*	-.12	-.11	-.05	.06	.12	.00	.87**	.53**						
14. AGREEABLENESS	-.08	-.19*	-.06	.19*	.35**	.51**	-.02	.28**	.19*	.29**	.01	-.02	.04					
15. Cooperativeness	-.15	-.17*	.05	.23**	.41**	.56**	.00	.37**	.27**	.37**	-.03	-.07	.01	.86**				
16. Politeness	.02	-.13	-.17*	.10	.19*	.31**	-.05	.10	.05	.13	.06	.04	.07	.85**	.48**			
17. OPENNESS	.11	-.23**	-.15	.14	.27**	.36**	.01	.31**	.23**	.30**	.15	.11	.15	.40**	.39**	.29**		
18. Openness to culture	.30**	-.10	-.19*	.17*	.13	.13	.06	.26**	.21*	.24**	.27**	.22**	.26**	.20*	.144	.20*	.81**	
19. Openness to experience	-.12	-.26**	-.04	.06	.30**	.46**	-.04	.23**	.16	.24**	-.03	-.04	-.01	.44**	.49**	.26**	.78**	.28**

Note. *n*=140; *$p < 0.05$. **$p < 0.01$. [a]Gender was a dichotomous variable (0=female; 1=male).

2.3.2.2 Hierarchical regression analyses

Major personality traits as predictors of objective visuo-spatial abilities and self-assessed visuo-spatial inclinations.

In the case of the objective visuo-spatial abilities, all the predictors explained 41% of the variance, and the final model was significant, $F_{(7,132)}=13.30$, $p<.001$. In Step 1, age and gender accounted for a significant, moderate portion of variance (35%, $p<.001$), with a significant contribution only of age (see Table 2.5). In Step 2, personality traits accounted for an additional significant, but small portion of variance (6%, $p<.05$), with a significant contribution of Conscientiousness (see Table 2.5).

As for the self-assessed visuo-spatial inclinations, all the predictors explained 31% of the variance, and the final model was significant, $F_{(7,132)}=8.43$, $p<.001$. In Step 1, age and gender accounted for a small portion of variance (6%, $p<.05$), with a significant contribution only of gender (see Table 2.5). In Step 2, personality traits accounted for an additional significant moderate portion of variance (25%, $p<.001$), with a significant contribution coming from Conscientiousness and Emotional Stability (see Table 2.5).

Table 2.5. *Hierarchical regression analyses with age, gender and personality traits as predictors for the composite scores for objective visuo-spatial abilities and self-assessed visuo-spatial inclinations, respectively.* R_2, ΔR_2, *and standardized* β *concern each step.*

	Objective visuo-spatial abilities		Self-assessed visuo-spatial inclinations	
	Model 1	Model 2	Model 1	Model 2
	β	β	β	β
Age	-.58***	-.63***	.05	-.00
Gender[a]	.12	.05	.24**	.21**
ENERGY		-.12		.06
CONSCIENTIOUSNESS		.15*		.33***
EMOTIONAL STABILITY		.13		.28***
AGREEABLENESS		-.08		.13
OPENNESS		-.06		-.01
R_2	.35***	.41***	.06*	.31***
ΔR_2		.06*		.25***

Note. *n*=140; **p* < .05. ***p* < .01. ****p* < .001. [a]Gender was a dichotomous variable (0=female; 1=male).

Narrower facets of personality as predictors of objective visuo-spatial abilities and self-assessed visuo-spatial inclinations.

As regards the objective visuo-spatial abilities, all the predictors explained 46% of the variance, and the final model was significant, $F_{(12,127)}=9.12$, $p<.001$. In Step 1, age and gender accounted for a significant moderate portion of variance (36%, $p<.001$), with a significant contribution only from age (see Table 2.6). In Step 2, personality facets accounted for an additional significant, but only modest portion of variance (10%, $p<.01$), with a significant contribution coming from Dynamism, Emotion Control and Politeness (see Table 2.6).

When self-assessed visuo-spatial inclinations were considered, all the predictors explained 37% of the variance, and the final model was significant, $F_{(12,127)}=6.00$, $p<.001$. In Step 1, age and gender accounted for a small portion of variance (6%, $p<.05$), with a significant contribution only of gender (see Table 2.6). In Step 2, personality facets accounted for an additional significant moderate portion of variance (31%, $p<.001$), with a significant contribution coming from Perseverance, Emotion Control and Cooperativeness (see Table 2.6).

Table 2.6. *Hierarchical regression analyses with age, gender and personality facets as predictors for the composite scores for objective visuo-spatial abilities and self-assessed visuo-spatial inclinations, respectively. R_2, ΔR_2, and standardized β concern each step.*

	Objective visuo-spatial abilities		Self-assessed visuo-spatial inclinations	
	Model 1	Model 2	Model 1	Model 2
	β	β	β	β
Age	-.58***	-.61***	.05	.00
Gender[a]	.12	.02	.24**	.18*
Dynamism		-.21*		-.07
Dominance		-.05		.06
Scrupulousness		.09		.16
Perseverance		.02		.19*
Emotion Control		.22**		.37***
Impulse Control		-.08		-.06
Cooperativeness		.18		.22*
Politeness		-.17*		.01
Openness to Culture		.01		.02
Openness to Experience		-.08		-.02
R_2	.36***	.46***	.06*	.37***
ΔR_2		.10**		.31***

Note. *n*=140; **p* < .05. ***p* < .01. ****p* < .001. [a]Gender was a dichotomous variable (0=female; 1=male).

2.4 Discussion

This study newly investigated in young and older adults whether, and to what extent, major traits and narrower facets of personality – envisaged in the Big Five model (Goldber, 1992) - influence individuals' visuo-spatial factors in terms of both objective visuo-spatial performance (in tasks involving rotation and VSWM abilities), and self-assessed visuo-spatial inclinations (involving pleasure and anxiety in exploring places).

First, the results of factor analysis confirmed that the visuo-spatial measures considered can be divided into two factors, represented by objective visuo-spatial abilities on the one hand, and by self-assessed visuo-spatial inclinations on the other, consistently with previous evidence (e.g., Hegarty et al., 2006). They also confirmed that objective visuo-spatial abilities include rotation abilities and VSWM (e.g., Hegarty et al., 2006), which respectively represent high-order visuo-spatial skills and visuo-spatial processing abilities.

The results from regression analyses confirmed the role of age (in line with the findings emerging from correlations analyses) in predicting a larger part of the variance -than personality traits- in objective visuo-spatial task performance (35%), but not in self-assessed visuo-spatial inclinations. This pattern of results confirms that older people encounter greater difficulties than younger adults in tasks that involve processing and manipulating visuo-spatial information (Borella et al., 2014; Mammarella et al., 2013), while their self-assessed visuo-spatial inclinations do not change over time (Borella et al., 2014; De Beni et al., 2014).

Gender was found to account for a significant, but small portion of variance in self-assessed visuo-spatial inclinations (in favor of men), in line with previous reports across the adult life span (De Beni et al., 2014), but did not influence objective visuo-spatial task performance (as also shown by the correlation analyses). It is worth noting that the few aging studies on gender-related differences in visuo-spatial task performance either found no gender effects (Kaltner & Jansen, 2016) or, at most, found them only modest (by comparison with the effects of age) and dependent on the visuo-spatial task considered (e.g., Borella et al., 2014; Techetin, Vojer & Vojer, 2014; Vojer & Vojer, 2017; Wang, Cohen, & Carr, 2014).

More interestingly, beyond the role of age and gender, personality traits (and their facets) predicted both objective visuo-spatial performance and self-assessed visuo-spatial inclinations, albeit to a variable extent.

Concerning objective visuo-spatial abilities, they were only predicted by Conscientiousness, and only weakly. Our pattern of findings is in line with the general notion that higher Conscientiousness is associated with a better cognitive performance - and objective visuo-spatial tasks performance in the case in point (e.g., Curtis et al., 2015; Luchetti et al., 2015). This seems to contrast, however, with previous reports of a higher Openness and lower Agreeableness being associated with a better performance in tasks demanding mental rotation (Schaie et al., 2004), and of these two traits, combined with lower Extraversion and lower Neuroticism (i.e., higher Emotional Stability) being associated with a better performance in spatial visualization and reasoning tasks (see Chapman et al., 2017; Graham & Lachman, 2014; see also Sharp et al., 2010; Soubelet & Salthouse, 2010; 2011). Possible explanations for such contrasting findings might relate to the features of the tasks considered here. Unlike those used in previous studies, our tasks had either time constraints (5 minutes for the sMRT and sOPT), or processing demands that increased when participants performed well (all those measuring VSWM). Participants thus needed to be able to organize their time and optimize their resources to complete the task successfully in the former case, or to exert greater attentional control and use more processing resources in the latter. It may be that the greater commitment, organization and persistence characteristic of Conscientiousness helped our participants to perform better in our demanding tasks, overshadowing the role of other major traits, which might be useful in other types of visuo-spatial task with different requirements (Chapman et al., 2017; Graham & Lachman, 2014; Schaie et al., 2004; Sharp et al., 2010; Soubelet & Salthouse, 2010; 2011). It is noteworthy that the correlation analyses did not show any significant relationships between objective visuo-spatial abilities and such a major personality trait. This might be because regression analyses, unlike correlation analyses, bring out the significant contribution of traits (and Conscientiousness in particular), after controlling for age and gender, and also for the effects of the other personality traits considered.

Looking specifically at the contribution of the narrower facets of personality, we found -in line with the correlation analyses- that a better performance in objective visuo-spatial tasks was predicted by higher Emotion Control (a facet of Emotional Stability) and Politeness (a facet of Agreeableness) - consistently with previous findings when only the main traits were examined (Baker et al., 2006; Chapman et al., 2017; Graham & Lachman, 2014; Schaie et al., 2004; Sharp et al., 2010; Soubelet & Salthouse, 2010; 2011), and also by lower Dynamism (a facet of Extraversion/Energy). It is worth mentioning that two previous studies involving young and older adults, and seeking a relationship between personality facets and visuo-spatial performance also found lower scores on Assertiveness, which is a facet of Agreeableness (Graham & Lachman, 2014), and on Depression and Anxiety, which are facets of Neuroticism/Emotional Stability (Chapman et al., 2017; Graham & Lachman, 2014) associated with a better spatial visualization and reasoning performance. It might be thus argued that performance in tasks demanding the processing and manipulation of visuo-spatial information could be broadly facilitated by being: better able to handle and control negative emotions (have greater Emotion Control); less active and enthusiastic in interpersonal relations (lower Dynamism); less kind and empathic towards other people (lower Politeness); and possibly more focused on investing resources in demanding tasks and in one’s own intellectual achievement than in social interactions (Graham & Lachman, 2014; Soubelet & Salthouse, 2011).

The different associations that emerged between personality traits or their narrower facets and objective visuo-spatial performance (i.e., Conscientiousness, but not its facets, or the facets of Emotion Control, Politeness and Dynamism, but not the major traits they reflect) might be due to facets having a specific variance unrelated to the traits they express (Costa et al., 2018; Hofstee et al., 1992; Mõttus et al., 2017), and thus making unique contributions to the depiction of personality (Costa et al., 2018; Hofstee et al., 1992; McCrae, 2915; Mõttus et al., 2017). Different associations between personality and cognition (visuo-spatial abilities in our case) might thus emerge when broad domains as opposed to narrower facets of personality are considered. Further, a possible explanation for the different association between personality and objective visuo-spatial performance (as considered here) or fluid intelligence (as considered in previous studies) might also be that the latter are conceived as two distinct sub-factors of intelligence (Colom, Abad, Rebollo, & Shih, 2015; Martínez et al., 2011). It has already been suggested that different associations between personality and intelligence might emerge when different combinations of hierarchical levels of personality and intelligence are considered (Kretzschmar, Spengler, Schubert, Steinmayr, & Ziegler, 2018; Reeve, Meyer, & Bonaccio, 2006).

It is worth stressing that the contribution of personality in influencing objective visuo-spatial abilities was modest (see Ackerman, 2018; Curtis et al., 2015; Schaie et al., 2004). It might be that situational factors relating to the tests (e.g., whether feedback on performance is provided), or other individual characteristics (e.g., motivation and engagement; Moè, Meneghetti, & Cadinu, 2009; Hess, 2014) have played a part (Ackerman & Heggestad, 1992; Ackerman, 2018; Schaie et al., 2004). It could also be that personality has a role when tasks involve managing meaningful information, unlike laboratory-based visuo-spatial tasks (like those used here), or in more ecological situations (Ackerman, 2018). These are only speculations, which would deserve further investigation.

Turning now to self-assessed visuo-spatial inclinations, our regression analyses -in line with the pattern of correlations- showed that higher Conscientiousness and Emotional Stability positively predicted a moderate portion of the variance (25%) in these self-assessed visuo-spatial inclinations, coinciding with higher pleasure in exploring places and lower spatial anxiety. The contribution of narrower personality facets was at least partly similar to those of major traits: higher Scrupulousness (a facet of Conscientiousness), Emotion Control (a facet of Emotional Stability), and also Cooperativeness (a facet of Agreeableness) positively predicted a moderate portion of the variance in self-assessed visuo-spatial inclinations. These findings newly extend also to older adults the previously-reported finding that young adults' personality traits and facets influence their self-reported visuo-spatial inclinations when exploring and visiting places (see Pazzaglia et al., 2018). Further, unlike our findings for objective visuo-spatial abilities, the facets seemed to better capture the associations between those aspects of the broad personality traits they represent and self-assessed visuo-spatial inclinations (Costa et al., 2018; Hofstee et al., 1992; Mõttus et al., 2017). It could be that individuals' personality - and commitment, emotional control, kindness and sensitivity towards others in particular - might influence their positive or negative attitudes to exploring, and how they typically engage and interact with the environment from both an affective and a behavioral standpoint (e.g., Condon et al., 2015; see also Bryant, 1982). Self-reported inclinations could thus be conceived as the expression of personality in environment-related situations.

Overall, the present findings indicate that, beyond the role of age and gender, different personality traits and facets have a weak influence on objective visuo-spatial abilities, but a stronger effect on self-assessed visuo-spatial inclinations.

3. Study 2: Explaining age-related differences between young and older adults' rotation ability: what about using the Walking Corsi Test?

3.1 Rationale and aims of the study[2]

Given the role of a core cognitive mechanism such as visuo-spatial working memory (VSWM) in supporting individuals' visuo-spatial abilities, such as rotation (e.g., Borella, Meneghetti, Ronconi, & De Beni, 2014; Hegarty & Waller, 2005; Meneghetti, Borella, Pastore, & De Beni, 2014), which are crucial to several everyday spatial activities (e.g., spatial orientation and route learning) and essential for the everyday mastery of the environment (e.g., Meneghetti et al., 2014; see Klencklen et al., 2012; Lester, Moffat, Wiener, Barnes, & Wolbers, 2017; Moffat, 2009, Techetin, Vojer & Vojer, 2014 for reviews), it is therefore important to identify new measures to assess it.

VSWM is usually assessed with visuo-spatial tasks that involve handling visuo-spatial stimuli presented on boards, sheets of paper, or computer screens (e.g., Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). In Study 2 VSWM was newly assessed in young and older adults with an extended version of a classic VSWM measure, i.e., the backward Corsi Blocks Task (CBT; Corsi, 1972), called the backward Walking Corsi Test (WalCT; Piccardi et al., 2019), which involves recalling sequences of spatial locations while moving around in a controlled setting.

The study, thus, aimed to thoroughly explore the relationship between this VSWM task and classic VSWM measures, to ascertain its concurrent validity, and its association with self-assessed visuo-spatial attitudes to environment-related tasks. It has indeed been suggested that VSWM is related to both self-reported sense of direction and positive attitudes to exploring places, as well as with negative spatial attitudes such as spatial anxiety, across the adult life span (e.g., Borella et al., 2014; Meneghetti et al., 2014; but see Muffato, Meneghetti, Di Ruocco, & De Beni, 2017;

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[2] Study 2 has been described in Carbone, Meneghetti, Mammarella, & Borella (under revision).

Meneghetti, Borella, Muffato, Pazzaglia, & De Beni, 2014a). The relationship of the backward WalCT with individuals' self-assessments of their attitudes to performing environment-related tasks was also explored because this task entails moving around in the environment – albeit in a controlled setting (see Mitolo et al., 2015).

A further aim was to adopt a structural equation modeling approach to examine whether and to what extent the backward WalCT makes a specific contribution, beyond that of its classic version (the backward CBT), in explaining age-related effects on rotation performance (e.g., Briggs, et al., 1999; Borella et al., 2014; Meneghetti et al., 2014; Raz et al., 1999; Salthouse et al., 1989).

A sample of young and older adults completed the backward WalCT (Piccardi et al., 2019), along with the backward CBT (Piccardi et al., 2019; adapted from Corsi, 1972) and other well-established classic VSWM measures: the paper-and-pencil Jigsaw Puzzle Test (De Beni, Borella, Carretti, Marigo, & Nava, 2008; adapted from Richardson & Vecchi, 2002) and the computerized Pathways Span Task (adapted from Mammarella, Pazzaglia & Cornoldi, 2008; Cornoldi et al., 1999). As for rotation ability, two well-established paper-and-pencil tasks were administered: the Mental Rotations Test (De Beni, Meneghetti, Fiore, Gava & Borella, 2014; adapted from Vandenberg & Kuse, 1978); and the Object Perspective Test (De Beni et al., 2014; adapted from Kozhevnikov & Hegarty, 2001). For self-assessed visuo-spatial inclinations, we focused here on positive and negative attitudes to environment-related tasks, i.e. pleasure in exploring places and spatial anxiety, measured with the Attitude to Orientation Task (De Beni et al., 2014; see Muffato, Toffalini, Meneghetti, Carbone & De Beni, 2017), and the Spatial Anxiety scales (De Beni et al., 2014; adapted from Lawton, 1994), respectively.

Since the backward WalCT - like other complex VSWM tasks (see Logie, 2011) - demands processing resources and attentional control that are known to decline with aging (e.g., Borella et al., 2008; see Mammarella et al., 2013), we expected older adults to perform less well than young adults in this task. In line with the literature, we expected to confirm age-related differences in favor of young adults in the classic VSWM measures and rotation tasks, but no differences between the two age groups in their self-assessed visuo-spatial inclinations, which are considered fairly stable individual characteristics (e.g., Borella et al., 2014; Mammarella, Borella, Pastore, & Pazzaglia, 2013).

We expected the backward WalCT to show significant associations with the classic VSWM measures, as well as with rotation tasks, in line with the evidence that such a core cognitive mechanism and high-order rotation ability share the same spatial and attentional resources for storing and processing visuo-spatial information (e.g., Bruyer & Scailquin, 1998; Cornoldi & Mammarella, 2008; Hegarty & Waller, 2005; Hyun & Luck, 2007; Wang & Carr, 2014; Wang et al., 2018).

Concerning the association between the backward WalCT and self-assessed pleasure in exploring or spatial anxiety, we might expect to find some, probably small associations, as previously reported (e.g., Borella et al., 2014; Meneghetti et al., 2014; Mitolo et al., 2015). On the other hand, no associations between the backward WalCT and visuo-spatial self-assessments might be expected, in line with previous studies adopting an age-related differences perspective for VSWM tasks (e.g., Muffato et al., 2017; Meneghetti et al., 2014).

Finally, we explored whether and to what extent the backward WalCT can make a specific contribution, beyond its classic version (the backward CBT), to explaining age-related effects on rotation ability. We expected age to have a direct effect on rotation ability (e.g., Borella et al., 2014). We also expected to confirm that VSWM - as measured with the backward CBT and the backward WalCT - mediates age-related differences between young and older adults' rotation performance (e.g., Briggs et al., 1999; Borella et al., 2014; Kantler & Jansen, 2016; Raz et al., 1999).

3.2 Method

3.2.1 Participants

Seventy young adult (age range: 18-34 years; 36 females) and 56 older adult (age range: 65-75 years; 32 females) community dwellers recruited by word of mouth or through associations in north-eastern Italy volunteered for the study. The inclusion criteria were as follows: a good physical and mental health status, assessed by means of a semi-structured interview (De Beni et al., 2008); and, for older adults, a Mini-Mental State Examination score (Folstein, Folstein & McHugh, 1975) above the cut-off of 27. Table 3.1 shows participants' demographic characteristics. The two age groups did not differ in terms of educational level (see Table 3.1), or gender distribution (χ_2=0.49, *p*=.53).

Table 3.1. *Means (M) and standard deviations (SD) of demographic characteristics by age group.*

	Young adults N=70 (36 females)		Older adults N=56 (32 females)	
	M	*SD*	*M*	*SD*
Age	23.51	2.95	68.23	2.99
Education (in years)	12.74	0.65	12.46	0.97

3.2.2 Materials

Visuo-spatial working memory

Backward Walking Corsi Test (WalCT; Piccardi et al., 2019). This larger-scale version of the CBT (scale 10:1) is set up in a room (5 x 6 m in size), where 9 squares (30 x 30 cm) are placed inside a 3 x 2.5 m rectangle drawn on the floor in the same scattered layout as in the CBT, and curtains are placed around this configuration to hide all external landmarks (i.e., doors, heaters, windows etc.). The task has shown a good reliability (Cronbach's alpha= .90). The experimenter and participant start from the same point outside the configuration. The experimenter charts a path, moving from one location (i.e., a square) to the next in a sequence, and stopping at each location for 2 s. Then participants are asked to repeat the sequence of locations in reverse order as they walk around within the configuration. The sequences of locations to recall gradually increase in length (from 2 to 9 squares). Five sequences are presented for each length, and participants have to repeat at least 3 of the 5 sequences of the same length correctly, otherwise the task is abandoned. The final score (the dependent variable) is the number of locations in the longest correctly-recalled sequence (Score:

minimum 2 - maximum 9).

Backward Corsi Blocks Task (CBT; Piccardi et al., 2019; adapted from Corsi, 1972). In this task, blocks (3 x 3 x 3 cm) are placed at random on a board (30 x 25 cm) and the experimenter taps a sequence of blocks, stopping on each block for 2 sec. Then participants are asked to repeat the same sequence of blocks, but in reverse order. The number of blocks in a sequence gradually increases in length (from 2 to 9 blocks). Five sequences are presented for each length, and participants have to repeat at least 3 of the 5 sequences of the same length correctly, otherwise the task is abandoned. The task has shown a good reliability (Cronbach's alpha=.94). The final score (the dependent variable) is the number of blocks in the longest sequence correctly recalled (minimum 2 - maximum 9).

Jigsaw Puzzle test (Puzzle; De Beni et al., 2008, adapted from Richardson & Vecchi, 2002). This task consists of 27 drawings of common objects, each broken down into numbered pieces forming a puzzle. The task has shown a good reliability (Cronbach's alpha=.83). Each whole drawing is presented together with a corresponding verbal label for 2 sec, then it is hidden. Participants are given the numbered pieces and asked to complete the puzzle, mentally recomposing the figure by indicating where the corresponding pieces should go on a blank matrix, without actually moving them (time constraint for each figure: 90 sec). The complexity of the task varies, depending on the number of pieces forming a given figure (from 2 to 10). The final score (the dependent variable) is the sum of the levels corresponding to the three most difficult puzzles correctly completed.

Pathways Span Task (PST; adapted from Mammarella et al., 2008, Cornoldi et al., 1999). In this computerized version of the original task, which has shown a good reliability (Cronbach's alpha=.85), a matrix with a colored cell in the south-west corner is presented on the screen for 4 sec, and then disappears. Participants are asked to mentally imagine following a path on the matrix, starting from the colored cell, based on directions (i.e., forwards, backwards, left, or right) indicated by sequences of arrows (i.e., up, down, left, right) that appear on the screen one at a time for 2 sec each, with an inter-stimulus interval of 1 sec. Finally, a blank matrix appears and participants are asked to indicate the final position reached. The difficulty of the task varies according to the size of the matrix (from 2 x 2 to 6 x 6 cells) and the length of the path (the number of displacements indicated by the arrows). The final score (the dependent variable) is the sum of the levels corresponding to the three most complex trials completed correctly.

Rotation ability

Short Mental Rotations Test (sMRT; De Beni et al., 2014, adapted from Vandenberg & Kuse, 1978). This task involves identifying two of four abstract 3D objects that match a target object in a rotated position, and has shown a good reliability (Cronbach's alpha=.81). Participants are shown 10 items to complete in 5 min. The final score (the dependent variable) is the number of correct answers (minimum 0 - maximum 10).

Short Object Perspective Test (sOPT; De Beni et al., 2014, adapted from Kozhevnikov & Hegarty, 2001). This task involves looking at a layout of seven objects and imagining standing alongside one object, facing another, and pointing to a third. The layout remains visible to participants and a circle is used to provide the answer. The task has shown a good reliability (Cronbach's alpha=.80). Participants have to complete 6 items with a time constraint of 5 min. The absolute angle of error is calculated for each item in degrees of difference between the correct angle and the one indicated by participants. The final score (the dependent variable) is the mean error in degrees (range 0°-180°), so higher scores correspond to a worse performance.

Self-assessed visuo-spatial inclination

Attitudes to Orientation Tasks scale (AtOT; De Beni et al., 2014, see Muffato et al., 2017 for an English translation of the scale). This scale comprises 10 items assessing pleasure (e.g., "I like to find new ways to reach familiar places"; 5 items) and no pleasure (e.g., "When I see a new road, I avoid taking it because I don't know where it ends"; 5 items) in exploring. It has shown a good reliability (Cronbach's alpha .83 and .78, respectively). Participants rate each item on a Likert scale from 1 (not at all) to 6 (very much). The score is calculated as the reverse of the rating on the items indicating no pleasure in exploring, so the final score expresses the respondent's pleasure in exploring (minimum 10 - maximum 60).

Spatial Anxiety scale (SA; De Beni et al., 2014, adapted from Lawton, 1994). This scale comprises 8 items assessing the degree of space-related anxiety experienced in an environment (e.g., "Going to an appointment in an unfamiliar part of the city"), and has shown a good reliability (Cronbach's alpha=.87). Answers are given on a Likert scale from 1 (not at all) to 6 (very much). The final score is the sum of the ratings for each item (minimum 8 - maximum 48), with higher scores corresponding to greater spatial anxiety.

3.2.3 Procedure

Participants attended two individual sessions of approximately 60 min each. At the start of the first session, after signing an informed consent form, all participants completed a general information questionnaire (and the MMSE for the older participants). The visuo-spatial tasks and visuo-spatial self-assessments were then administered across the two sessions in two sets: one included the sMRT, backward CBT, PST and AtOT scale; the other the Puzzle, WalCT, and sOPT. The SA scale was always presented at the very end of the second session.

3.3 Results

First, ANOVAs were run for the WalCT, the three VSWM tasks, the two mental rotation tasks, and the two spatial self-assessments, with age group (young adults vs older adults) as the independent variable[3]. Table 3.2 shows the results and corresponding descriptive statistics by age group. The young adults outperformed the older adults in the backward WalCT, and in all the VSWM

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[3] Preliminary MANCOVAs with age group (young adults vs older adults) as the independent variable and gender as the covariate revealed no effects of the covariate on any of the VSWM measures ($F_s<1$), or the sOPT, $F_{(1,123)}= 2.83$, $p=.09$, $\eta^2_p= .04$. Instead, there was a significant effect of gender (in favor of men) on the sMRT, $F_{(1,123)}=7.15$, $p<.01$, $\eta^2_p= .05$, and the two spatial self-assessments (AtOT: $F_{(1,123)}=4.96$, $p<.05$, $\eta^2_p=.03$; SA: $F_{(1,123)}=6.65$, $p<.05$, $\eta^2_p= .05$). In the light of our findings, and of previous evidence in aging studies of gender effects being generally modest - by comparison with the large negative effects of age - in accounting for performance in visuo-spatial measures (e.g., Kantler & Jansen, 2016; Techetin 2014; see also Borella et al., 2014), we chose not to consider the role of gender in subsequent analyses.

and rotation tasks (see Table 3.2), while the two age groups did not differ significantly in the two spatial self-assessment scores (see Table 3.2).

Table 3.2. *Means (M) and standard deviations (SD) for the visuo-spatial tasks and visuo-spatial self-assessments by age group (young adults vs older adults), and results of ANOVAs.*

	Young adults (N=70)		Older adults (N=56)		Young adults vs Older adults			
	M	*SD*	*M*	*SD*	*F*	df	*p*	η^2_p
Visuo-spatial working memory:								
Backward Walking Corsi Test	5.22	0.74	4.23	0.63	63.49	1,124	<.001	.34
Backward Corsi Blocks Task	5.25	0.94	4.37	0.70	33.92	1,124	<.001	.21
Jigsaw Puzzle test	22.00	4.38	17.50	3.47	39.17	1,124	<.001	.26
Pathways Span Task	24.65	4.81	18.87	4.85	44.25	1,124	<.001	.24
Rotation ability:								
short Mental Rotations Test	4.38	2.55	2.35	1.48	27.78	1,124	<.001	.18
short Object Perspective Test	32.68	24.48	57.28	36.74	20.18	1,124	<.001	.14
Self-assessed visuo-spatial inclinations:								
Attitudes to Orientation Tasks scale	34.04	7.27	34.91	8.43	<1	1,124	.53	.003
Spatial Anxiety scale	22.28	6.42	21.14	6.21	1.01	1,124	.31	.01

3.3.1 Correlations

Pearson's correlations were run between age, the backward WalCT, the classic VSWM tasks, the rotation tasks, and the spatial self-assessments. The results are shown in Table 3.3.

Age showed medium-to-large correlations with the backward WalCT (*r*=-.58, *p*<.01), the three VSWM tasks (*r*s from -.51 to -.48), and the two rotation tasks (*r*=-.43, *p*<.01 for the sMRT and *r*=.38, *p*<.01 for the sOPT, older age being associated with greater angular error scores), older age being associated with worse scores (see Table 3.3). No significant correlation emerged between age and the two spatial self-assessments (see Table 3.3).

Medium-to-large correlations were found between the backward WalCT and the other VSWM tasks. In particular, there was a large positive correlation between the backward WalCT and the backward CBT (*r*=.61, *p*<.01), and medium correlations for the backward WalCT with the Puzzle (*r*=.43, *p*<.01) and the PST (*r*=.47, *p*<.01).

Significant medium correlations were also found for the backward WalCT (and the other classic VSWM measures) with the two rotation tasks (see Table 3.3).

The backward WalCT did not correlate with either of the two spatial self-assessments (see Table 3.3).

Table 3.3. *Correlations between age, visuo-spatial tasks and spatial self-assessments.*

	1	2	3	4	5	6	7	8
1. Age	-							
2. Backward Walking Corsi Test	-.58**							
3. Backward Corsi Blocks Task	-.48**	.61**						
4. Jigsaw Puzzle test	-.49**	.47**	.37**					
5. Pathways Span Task	-.51**	.43**	.39**	.42**				
6. short Mental Rotations Test	-.43**	.51**	.41**	.54**	.32**			
7. short Object Perspective Test	.38**	-.45**	-.47**	-.36**	-.47**	-.41**		
8. Attitudes to Orientation Tasks scale	.07	.07	.03	.12	-.08	.17	.03	
9. Spatial Anxiety scale	-.09	-.16	-.06	-.15	.01	-.23**	0.15	-.54**

**p* < .05, ***p* < .01, ****p* < .001

3.3.2 Structural equation model

The relationship between age, VSWM (as measured by means of the backward WalCT and the classic backward CBT) and rotation ability measures was further investigated, also in the light of the pattern of correlations that emerged.

To ascertain whether and to what extent the backward WalCT contributes, beyond the backward CBT, to mediating the age-related effects on rotation performance, a mediation model was tested using the R software (R Core Team, 2016) with the "lavaan" package (Rossel, 2012). Maximum likelihood was used to estimate the parameters of the models. The following indices were used to assess the goodness of fit: Comparative Fit Index (CFI; [0,1], large is good); Tucker-Lewis Index (TLI; [0,1], large is good); Standardized Root Mean Square Residual (SRMR; ≥0, small is good); Root-mean-Square Error of Approximation (RMSEA; ≥0, small is good).

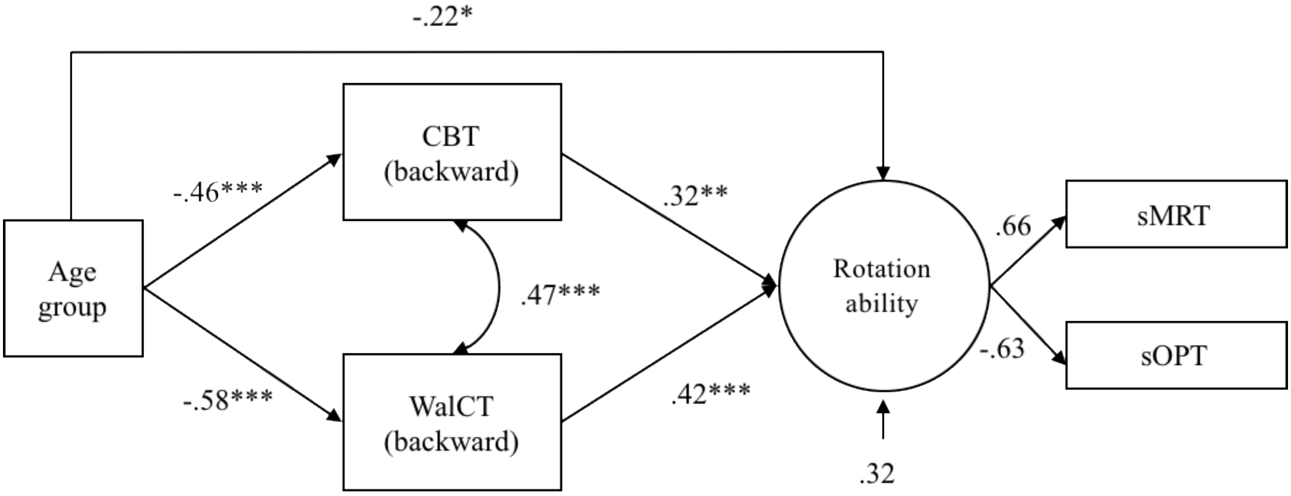
The model assumed that the age-related differences in rotation performance were mediated by VSWM, as measured with the backward CBT and the backward WalCT. The model thus tested the direct effect of age group on VSWM and rotation ability, which are known to be sensitive to age-related decline (Borella et al., 2014; Mammarella et al., 2013), as well as the indirect effect of age group on rotation ability through VSWM, in line with previous evidence (e.g., Briggs, et al., 1999; Borella et al., 2014; Kantler & Jansen, 2016; Raz et al., 1999). Rotation ability was represented by the two rotation tasks (sMRT, sOPT), which showed a medium correlation (r=-.41, p<.01), in line with previous findings, and were treated as a single latent factor (e.g., Meneghetti et al., 2014). The two VSWM tasks were entered as separate variables in order to examine the specific contribution of the backward WalCT and of the classic backward CBT to explaining rotation performance.

The fit of the model, presented in Figure 3.1, was adequate, $\chi_{2(2)}$ = 2.11, p= .34, CFI = .99, TLI=.99, SRMR = .02, RMSEA= .02. Age had a direct effect on performance in both the backward CBT and the backward WalCT. Age also had a direct effect on rotation ability (ß=-.22, p<.05), and an indirect effect mediated by VSWM (indirect effect through the backward CBT: ß=-.15, p<.05;

indirect effect through the backward WalCT: ß=-.24, *p*<.01). Both the backward CBT (ß=.32, *p*<.01) and the backward WalCT (ß=.42, *p*<.001) were significant predictors of rotation performance.

Figure 3.1. *Structural model. The standardized solutions are presented for each path.*

**p* <.05*,* ***p* <.01*,* ****p* <.001



Note. WalCT (backward): backward Walking Corsi Test; CBT (backward): backward Corsi Blocks Task; sMRT: short Mental Rotations Task; sOPT: short Object Perspective Test.

3.4 Discussion

In this study a sample of young and older adults was administered the backward WalCT, a task never previously used in aging studies that involves handling and recalling sequences of spatial locations while moving in a controlled setting. The aim was to explore the backward WalCT's association with classic measures of VSWM and rotation ability, as well as with self-assessed visuo-spatial attitudes to environment-related tasks. A structural equation modeling approach was adopted to further explore whether the backward WalCT makes a specific contribution, beyond that of its classic version (the backward CBT), to mediating age-related effects on rotation performance.

First, and as expected, our findings showed that the backward WalCT is sensitive to age-related effects, since it demands processing resources and attentional control (Brown, 2016) that are known to decline with aging (e.g., Borella et al., 2008). Consistently with the literature, age-related differences in favor of young adults were also confirmed for all the classic VSWM measures (backward CBT, Puzzle, PST) (e.g., Brown, 2016; Mammarella et al., 2013), and for the rotation tasks (e.g., Borella et al., 2014; Techetin et al., 2014), while the two age groups did not differ in their spatial self-assessments, which are fairly stable individual characteristics (e.g., Borella et al., 2014).

In line with our expectations, the results of our correlation analyses showed medium-to-large correlations between the backward WalCT and the classic VSWM tasks, providing further evidence that the backward WalCT can be considered a measure of VSWM that requires processing resources and attentional control, as in VSWM complex span tasks (see Cornoldi & Vecchi, 2003; Fiore, Borella, Mammarella & Cornoldi, 2011; Logie, 2011; Mammarella et al., 2013).

Self-assessed visuo-spatial attitudes were found unrelated to performance in the backward WalCT or other classic VSWM measures. This is in line with previous studies adopting an age-related differences perspective (see, for example, Muffato et al., 2017; Meneghetti et al., 2014). Other spatial attitudes, such as self-reported sense of direction (see Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), or self-reported preference for visual, route (based on a personal point of view) or survey (based on a map view) strategies (see Münzer, Fehringer & Kühl, 2016) would be more likely to be related to performance in the backward WalCT, however, and further studies should consider this aspect.

The role of VSWM, as measured with the backward WalCT and the classic backward CBT, in mediating age-related effects on rotation ability was further examined using a structural equation model. As expected, age had a direct effect on performance in rotation tasks (e.g., Borella et al., 2014) and VSWM (e.g., Mammarella et al., 2013). Age also had an indirect effect on rotation ability, mediated by the backward CBT and -to a larger extent- by the backward WalCT. These findings further confirm that VSWM resources become crucial to complex spatial abilities such as mental rotation (e.g., Briggs et al., 1999; Borella et al., 2014; Kantler & Jansen, 2016; Raz et al., 1999), emphasizing age-related effects in rotation ability (e.g., Borella et al., 2014; Techetin et al., 2014, see also Kantler & Jansen, 2016).

More importantly, our results showed that the backward WalCT contributed, beyond the classic backward CBT, to explaining age-related effects on rotation performance. This seems to suggest that not only its classic version, but also the backward WalCT would be suitable for assessing the processing resources needed in complex visuo-spatial tasks, such as rotation tasks (see also Mitolo et al., 2015). A more thorough understanding of the association between VSWM and rotation ability could be gained by also using a task like the backward WalCT, as it elicits mechanisms involved in rotation tasks through a whole-body movement and involves a greater interaction with the environment. In other words, participants have to reorganize information about paths they have learned by watching sequences of locations charted by the experimenter, while also keeping track of their own location and continuously changing their perspective as they reproduce the sequences while walking through the configuration (e.g., Piccardi et al., 2013). Often-used visuo-spatial measures, like the backward CBT, entail managing meaningless stimuli or complex requests that are unfamiliar and unlikely to be linked to any prior knowledge - especially for older adults (e.g., Vecchi & Cornoldi, 1999). Instead, the backward WalCT might have the advantage of engaging participants more actively. It involves performing a task that is more likely to seem familiar to older adults, and interacting with a real-world environment - albeit in a controlled setting. This could have implications for their motivation and attitude to engaging in the task.

Overall, our findings show that the backward WalCT is sensitive to age-related effects, and helps to reveal age-related differences in complex spatial tasks, such as mental rotation, beyond the contribution of its classic version (the backward CBT). Being a tool that is easily-reproducible, feasible to administer, and engaging, the backward WalCT can therefore be considered one of the tasks particularly suitable for assessing VSWM in different age groups, and especially in older adults.

4. Study 3: How can we support route learning in older adults? The role of imagery strategy.

4.1 Rationale and aims of the study[4]

The use of strategies based on imagery, i.e., based on forming simple or more elaborate visual images of the information to be encoded, processed and manipulated in the mind's eye, have been shown to be the most effective in solving visuo-spatial tasks (Gluck & Fitting, 2003). To date, the benefit of practicing and using imagery strategy to support/improve visuo-spatial skills, in young adults at least, has been explored in relation to both rotation ability (Meneghetti, Cardillo, Mammarella, Caviola, & Borella, 2017) and spatial (route) learning (De Beni & Moè, 2003; Gyselinck, De Beni, Pazzaglia, Meneghetti, & Mondolini, 2007; Gyselinck, Meneghetti, De Beni, & Pazzaglia, 2009; Meneghetti, De Beni, Gyselinck & Pazzaglia, 2013). In this latter case, imagery strategy use favors the construction of better spatial representations of an environment, thus promoting the processing of spatial information and thereby facilitating young adults' spatial recall (e.g., Gyselinck et al., 2007; 2009; Meneghetti et al., 2013).

No studies have yet ascertained the beneficial role of practicing and using imagery strategy to perform route learning tasks in older adults, an ability that is known to be impaired with increasing age (e.g., Klencken, Deprés & Dofour, 2012; Lester, Moffat, Wiener, Barnes, & Wolbers, 2017). So far, evidence that older adults benefit from being instructed or trained to use imagery strategy has been collected, especially in relation to episodic memory performance (e.g., Craik & Rose, 2012; Herzog, Kramer, Wilson, & Lindenberger, 2008; Verhaeghen, Marcoen, & Goossens, 1992) and, broadly, in the verbal domain (see Ariel & Moffat, 2018; Craik & Rose, 2012). Concerning visuo-spatial tasks, there are only some suggestions that imagery strategy instructions promote benefits in older adults' rotation ability (Meneghetti, Carbone, Di Maggio, Toffalini, & Borella, 2018).

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[4] Study 3 has been described in Carbone, Meneghetti, & Borella (under revision).

In the light of the abovementioned evidence gained for young adults (e.g., Gyselinck et al., 2007; 2009; Meneghetti et al., 2013) and, in a broad sense, for older adults (e.g., Craik & Rose, 2012; Herzog et al., 2008; Verhaeghen et al., 1992), one way of helping older adults to preserve their route learning skills might be to train them to use effective encoding strategies, such as mental imagery (e.g., Craik & Rose, 2012; Herzog, Kramer, Wilson, & Lindenberger, 2008; Verhaeghen et al., 1992).

Study 2 thus aimed to explore the beneficial effect of practicing with an imagery strategy and using it to support spatial information processing and recall in young adults and, newly, in older adults as well.

Young and older adults were asked to learn a new route from a video, and then performed two tasks that involved recalling the landmarks encountered along the way in the right order, and locating them correctly on a layout of the environment. Before the route learning phase, participants were assigned to one of two learning groups: i) in one, the Strategy group (SG), they were sensitized on the use of imagery and given exercises in which they had to apply such a strategy, then they were advised and prompted to use the imagery strategy during the route learning phase; ii) in the other, the Control Group (CG), participants were involved in alternative activities and given no specific advice about how to approach the route learning phase.

We expected to confirm the age-related differences in route learning ability between young and older adults, in favor of the former (e.g., Klencklen et al., 2012; Lester et al., 2017).

As concerns the benefits of practicing with, and using imagery strategy, we expected young adults in the SG to perform better than young adults in the CG, in line with previous findings (e.g., Meneghetti et al., 2013).

Given the evidence of (episodic) memory performance in aging benefiting from being advised or taught to use imagery strategy (see Carretti, Borella & De Beni, 2007; Carretti, Borella, Zavagnin & De Beni, 2011; Craik & Rose, 2012; Herzog et al., 2008; Verhaeghen et al., 1992), we also expected older adults in the SG to outperform their peers in the CG when learning and recalling spatial information, i.e., learning a new route and recalling the sequence and locations of the landmarks encountered.

As for age-related differences between young and older adults, older adults might well benefit from practicing with and using imagery strategy, but to a lesser extent than young adults. In fact, the decline in spatial learning ability (e.g., Klencklen et al., 2012; Lester et al., 2017) and in the processing resources needed to implement self-initiated encoding strategies successfully in older age (e.g., Borella, Carretti & De Beni, 2008) could magnify the differences in route learning performance in favor of young adults (e.g., Craik & Rose, 2012; Luo, Hendrinks & Craik, 2007; Lövdén, Brehmer & Lindenberger, 2012). On the other hand, it may be that older adults taught to use imagery strategy could perform as well as young adults, thereby confirming not only that spatial performance is malleable (e.g., Lester et al., 2017), but also that older adults can compensate for their age-related decline in route learning ability by using effective encoding strategies.

4.2 Method

4.2.1 Participants

Forty young adults (age range 18-35) and 40 healthy older adults (age range 65-75) were involved in the study. All participants were Italian mother-tongue community dwellers recruited through associations in north-eastern Italy, or by word of mouth. The inclusion criteria were: a good physical and mental health status, assessed with a semi-structured interview (De Beni, Borella, Carretti, Marigo & Nava, 2008); and, for the older adults, a good cognitive functioning, based on the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975) score above the cut-off of 27.

Participants in each age group were randomly assigned to the SG (young adults=20, 10 females; older adults=20, 12 females), or the CG (young adults=20, 10 females; older adults=20, 12 females). Participants' demographics are shown in Table 1. The two age groups did not differ in terms of level education, $F_{(1,78)}<1$, or gender distribution (χ_2=.80, p=0.22), but young adults outperformed older adults in spatial reasoning measured with the Cattell test, $F_{(1,78)}=25.66$, $p<.001$, $\eta_{2p}=.24$ (Cattell & Cattell, 1973) (see Table 4.1).

Table 4.1. *Means (M) and standard deviations (SD) of the demographic characteristics and spatial reasoning (Cattell test) scores, by learning group for young and older adults.*

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	Young adults				Older adults			
	Strategy group N=20 (10 females)		Control group N=20 (10 females)		Strategy group N=20 (12 females)		Control group N=20 (12 females)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	23.70	2.86	23.80	3.27	68.50	3.80	68.80	3.31
Education (in years)	12.75	0.63	12.60	0.82	12.35	1.63	12.60	1.53
Cattell test	25.60	4.61	25.65	3.45	20.70	6.72	18.70	5.63

4.2.2 Materials

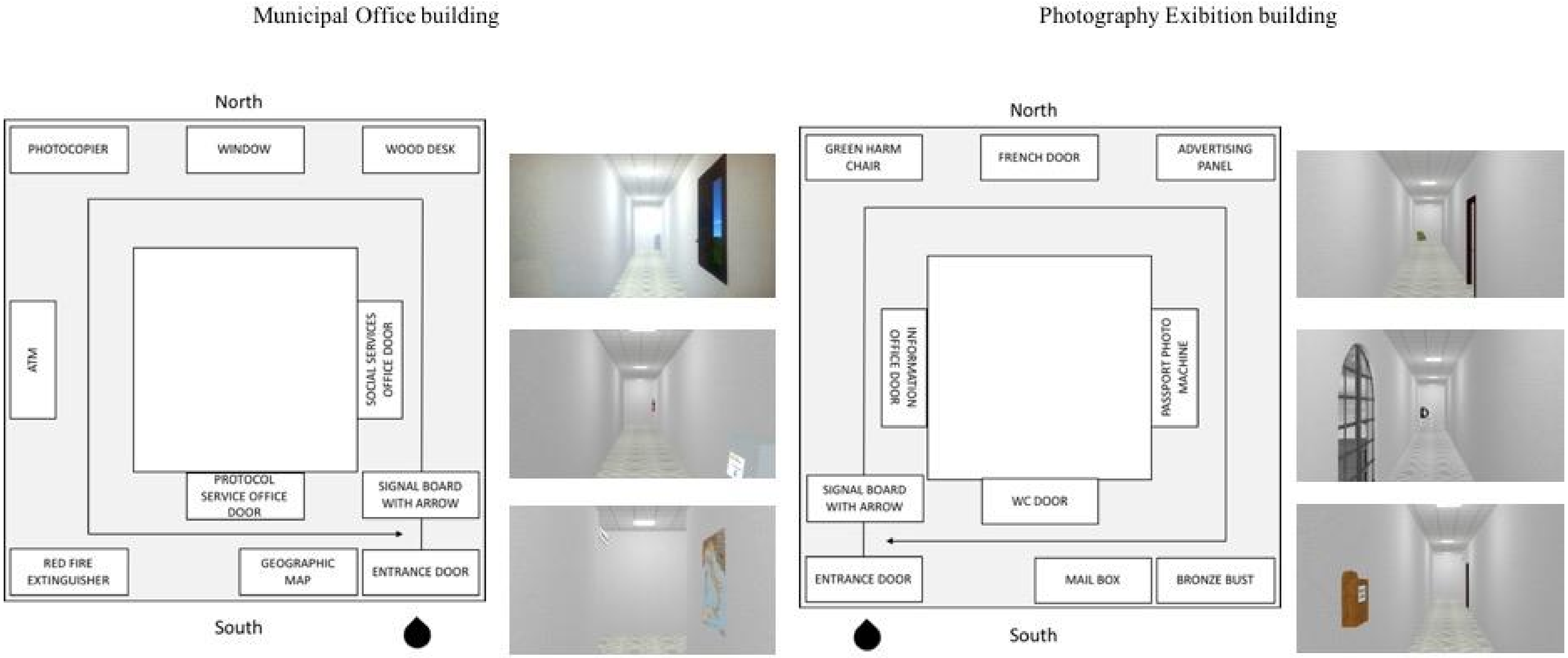
4.2.2.1 Environments for the route learning phase

There were two paths in two indoor environments, arranged on a square layout, i.e., the floors of a municipal office and a photography exhibition (Meneghetti, Borella, Carbone, Martinelli, & De Beni, 2016a). Both paths followed the perimeter of the square layout along four corridors, with three turns, ending back at the starting point. For both paths, ten landmarks were arranged along the left and right sides of the corridors and in the corners. Figure 4.1 shows the layouts of the two environments with the direction of the path navigated and the location of the landmarks. A reason for taking the path was provided at the beginning of presentation, i.e., to register for a summer holiday in the municipal office building, and to take part in a photo competition in the photography exhibition building. During the video, participants ‘interacted’ with 4 of the 10 landmarks (e.g., in the municipal office building there was a social services office where they stopped briefly to obtain an application form for the summer holiday) to underscore their reason for covering the path presented.

The two virtual-reality environments were modelled and animated using Blender software (version 2.67; www.blender.org). The final videos presenting the two environments from the participant's point of view, i.e., from a first-person perspective (see Figure 4.1 for examples), were saved as MPEG4 files. Each video lasted 2.32 min and was recorded at a constant walking speed (3.6 km/h).

During the route learning phase (see the Procedure section for details), all participants were familiarized with half of the path in one of the environments (familiarization), then learnt the whole path in the other (route learning). Both environments were shown to all participants in a counterbalanced fashion across the familiarization and route learning task.

Figure 4.1. *Layout (not shown to participants) of the two indoor environments showing the correct location of the landmarks, the starting point, the path and its direction, and the order in which landmarks were encountered along the way, with examples of views from the videos of both environments shown to participants.*



4.2.2.2 Recall tasks

Landmark ordering task (Meneghetti et al., 2016a). This involves placing 10 landmark labels showing the names of the landmarks in the same order as they were encountered along the path. The dependent variable was the sum of the landmarks recalled in the right order (maximum: 10).

Landmark locating task (Meneghetti et al., 2016a). This involves placing the 10 landmark labels showing the names of the landmarks in the right position on a 30 x 30 cm sheet representing the perimeter of the layout and the corridors in the environment. The dependent variable was the sum of the landmarks correctly positioned (maximum: 10).

4.2.2.3 Strategy questionnaires

Two ad hoc questionnaires were created: the Strategy Group Questionnaire (SGQ), to ascertain whether the SGs had actually used the imagery strategy learnt; and the Control Group Questionnaire (CGQ) to check for any spontaneous use of strategies by the CGs during the route learning task.

The SGQ involved rating: the level of detail of the mental representation of the route thanks to the use of the imagery strategy (Question 1); and how effective using the imagery strategy had proved (Question 2), on a Likert scale from 1 (very little) to 5 (very much).

In the CGQ respondents freely reported any strategies used during the route learning phase, which were then classified as in previous studies (e.g., Meneghetti, De Beni, Gyselinck & Pazzaglia, 2011) as: i) imagery-based visuospatial strategies (e.g., “I mentally took the path”, “I mentally drew a map of the environment”); or ii) verbal strategies (e.g., “I mentally repeated the name of the landmarks encountered”), or content-based strategies (e.g. “I memorized the sequence of the character’s actions along the path”).

4.2.3 Procedure

Participants attended 2 individual sessions lasting approximately 60 min each. In the first, after giving their informed consent, they provided general demographic and health-related information. All participants completed the Cattell test, and older adults also completed the MMSE.

The second session was dedicated to the route learning task, and divided into three phases: instructions; route learning; and recall (see Table 4.2).

In the SGs, the instructions phase lasted approximately 20 min, and was used to sensitize participants on the use of imagery strategy. First participants were given an explanation on imagery strategy use and its usefulness in everyday memory tasks (e.g., remembering a shopping list, or the route taken to a destination in a new city) (Introduction; see Table 4.2). Then they practiced with forming mental images of common objects (e.g., a pen, a book), and a path charted between 4 colored cubes placed at random on a sheet of paper (Practical part; see Table 4.2). In the route learning phase, half of the path in one of the two video-recorded indoor environments was used to familiarize participants with using imagery to memorize a path (Familiarization; see Table 4.2); then they learnt the whole path in the second environment, and were instructed and guided to use the imagery strategy (Route learning task; see Table 4.2). In the recall phase, participants completed the landmark ordering and landmark locating tasks, and the SGQ (see Table 4.2).

For the CGs, the structure and duration of the session was the same as for the SGs, but participants were involved in alternative activities in the first instructions phase: the experimenter discussed tasks that demand the use of memory in everyday life (e.g., remembering a shopping list, or the route to a destination in a new city), without mentioning the use and usefulness of strategies; and they completed two questionnaires (Introduction and Practical part; see Table 4.2). In the route learning phase, they were not given any guidance on the use of strategies, neither during familiarization nor in the route learning task (see Table 4.2 for details). In the recall phase, the CGs also completed the recall tasks, and then answered the CGQ (see Table 4.2).

Table 4.2. *Training given to the Strategy Groups and activities for the Control Groups in the second session.*

	Strategy Groups	Control Groups
Instructions phase	i) *Introduction*: the experimenter explained how to use imagery strategy and how it helps in everyday memory tasks. ii) *Practical part*: participants were asked to form mental images of common objects, some on the table (e.g., a pen, a book), others not in the room (e.g. an apple). Then, the experimenter charted a path with a chess piece between 4 colored cubes (5 cm) randomly placed on a sheet of paper (30 x 30 cm), and asked participants to imagine walking along the path, mentally visualizing their changes of direction, and the sequence and location of the cubes, in order to memorize them.  After each activity, participants were asked to provide feedback on whether they had used the imagery strategy, on the features of their mental images, and on the difficulty of the activities.	i) *Introduction*: the experimenter discussed activities and tasks that demand the use of memory in everyday life, without explaining how strategies can be used to perform them. ii) *Practical part*: participants completed two paper-and-pencil questionnaires: - the Memory Sensitivity Questionnaire (De Beni et al., 2008) involves rating the frequency of behavior dedicated to saving memories of life events; - the Psychological Well-Being Questionnaire (De Beni et al., 2008) involves rating personal satisfaction with life (past, present and future), emotional competence (ability to understand one's own and other's emotions), and strategies for coping with everyday problems. After completing each questionnaire, participants were asked for feedback on its content and how they had answered the questions.
Route learning phase	i) *Familiarization*: the experimenter showed the first part of a video of one of the indoor environments, stopping the video just before the first turn along the path. Participants were invited to use the imagery strategy, i.e., to mentally visualize the path, the elements encountered and their location along the corridors in the environment. Then the same was done with second part of the path (which ended immediately before the second turn). Finally, participants were invited to provide feedback on their use of the imagery strategy. ii) *Route learning task*: participants watched the video showing the path in the other environment twice, and were advised to use the imagery strategy to memorize it. During the first viewing, the experimenter paused the video immediately before the second turn, so participants saw 5 landmarks and two turns at a time. Participants were invited to apply the imagery strategy, and given time to mentally visualize the path, the landmarks and their location along the corridors in the environment, both halfway through the video, when it was paused, and at the end. During the second viewing, the whole path was presented without any pause. When the video came to an end, participants were reminded to use the imagery strategy, and given time to mentally visualize the path, the landmarks and their location along the corridors in the environment.	i) *Familiarization*: the materials used in the route learning task were presented and participants watched a part of one of the videos showing half of the path in one of the indoor environments. Participants were advised to pay attention to the path, but not given any specific instructions on the use of strategies to recall it. Participants were then invited provide feedback on the task and its demands. ii) *Route learning task*: participants watched the video showing the path in the other environment twice. They were advised to pay attention to the path, and to take their time to memorize it when the video was paused during the first presentation, but they were not given specific instructions on the use of strategies to perform the task.
Recall phase	Participants performed the landmark ordering and landmark locating tasks, then completed the Strategy Group Questionnaire.	Participants performed the landmark ordering and landmark locating tasks, then completed the Control Group Questionnaire.

4.3 Results

4.3.1 Strategy questionnaires

First, the answers provided by the SGs in the SGQ and by the CGs in the CGQ were checked to ascertain whether the former had used the imagery strategy they had been taught, and the latter had spontaneously used any strategies while performing the route learning tasks.

Both young and older adults in the SGs reported using the imagery strategy learnt, and no other types of strategy, which suggests that they followed the instructions they had received. Both age groups reported (F_s<1) being able to use the imagery strategy to obtain a detailed mental representation of the path (young adults: *M*=4.25, *SD*=0.71; older adults: *M*=4.10, *SD*=0.96), and judged the imagery strategy effective (young adults: *M*=4.15, *SD*=0.58; older adults: *M*=4.15, *SD*=1.09).

In the CGs, two young adults and four older adults reported not spontaneously using any strategy in the route learning task. Thirteen young adults and 10 older adults reported spontaneously using imagery-based visuospatial strategies. Five young adults and six older adults reportedly spontaneously used verbal or content-based strategies[5].

4.3.2 Recall tasks

Then, 2 (Age group: young adults vs older adults) x 2 (Learning group: SG vs CG) ANCOVAs were run separately on participants' accuracy in the landmark ordering and locating tasks[6]. The Cattell test score was used as a covariate, given the significant difference found between young and

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[5] Comparisons drawn with *t* tests revealed no differences in recall task performance between participants who reportedly spontaneously used imagery-based visuospatial strategies and those who reported using verbal or content-based strategies; this was true both of the young adults (landmark ordering task, *t*=1.11; *p*=.28; landmark locating task, *t*=0.61; *p*=.55), and the older adults (landmark ordering task, *t*=0.52; *p*=.60; landmark locating task, *t*=1.24; *p*=.23).

[6] The landmark ordering and landmark locating tasks were scored by two independent judges; the two judges' scores correlated closely (for landmark ordering: *r*=0.94, *p*<.01; for landmark locating: *r*=0.96, *p*<.01), so the analyses were run on the first judge's scores (i.e., those of the experimenter).

older adults. Descriptive statistics are given in Table 4.3, and the results of the ANCOVAs in Table 4.4.

Table 4.3. *Means (M) and standard errors (SE), adjusted for Cattell test scores, of the landmark ordering and locating tasks for the young and older adults, by learning group (SG vs CG).*

	Landmark ordering task						Landmark locating task					
	Strategy group		Control group		Total		Strategy group		Control group		Total	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Young adults	9.38	0.27	8.78	0.28	9.08	0.20	8.62	0.32	8.07	0.32	8.37	0.24
Older adults	8.58	0.27	6.92	0.29	7.76	0.21	8.08	0.32	5.66	0.33	6.87	0.24
Total	8.98	0.19	7.84	0.19			8.35	0.22	6.87	0.22		

The results showed a significant effect of the covariate only for the landmark locating task (see Table 4.4). The main effects of Age group emerged for both landmark ordering and landmark locating (see Table 4.4), young adults performing better than older adults in both tasks (p_s<.001). A significant main effect of Learning group also emerged for both recall tasks (see Table 5.4), with the SGs always outperforming the CGs (p_s<.001). The Age group x Learning group interaction was only significant for the landmark locating task (see Table 5.4). Pairwise comparisons indicated that older adults recalled landmark locations less well than young adults in the CG (p<.001), while in the SG they performed as well as the young adults (M_{diff}=0.54, p=.24). It was only among the older adults that the SG performed better than the CG (p<.001), while no differences emerged between young adult SG and CG (M_{diff}=0.55, p=.21).

Table 4.4. *Results of 2 (Age group: young adults vs older adults) x 2 (Learning group: Strategy Group vs Control Group) ANCOVAs on accuracy in landmark ordering and landmark locating tasks (with Cattell test scores as a covariate).*

Recall task	*F*	df	*p*	η_p^2
Landmark ordering				
Covariate (Cattell test)	2.39	1,75	.12	.03
Age group	18.11	1,75	<.001	.19
Learning group	17.40	1,75	<.001	.19
Age group x Learning group	3.83	1,75	.05	.04
Landmark locating				
Covariate (Cattell test)	9.19	1,75	<.01	.11
Age group	16.72	1,75	<.001	.18
Learning group	22.38	1,75	<.001	.23
Age group x Learning group	8.77	1,75	<.01	.10

4.4 Discussion

The present study investigated the benefit of using imagery strategy for route learning in young, and also for the first time in older adults. To do so, young and older adults either practiced with an imagery strategy, and were prompted to use it during a route learning task (the SGs), or they engaged in alternative activities before performing the same route learning task, without receiving any advice on how to approach it (the CGs).

Older adults were less accurate than young adults in recalling the landmarks encountered along the path in the right order and the right position, confirming (as expected) their greater route learning difficulties (e.g., Meneghetti et al., 2016; Muffato et al., 2016; 2018; see Colombo et al., 2017; Klencklen et al., 2012; Lester et al., 2017 for reviews).

The benefit of practicing with and using an imagery strategy was found: the SGs performed better than the CGs -regardless of age- in both spatial recall tasks. This result confirmed as expected that using an imagery strategy facilitates route learning in older adults too, as already seen in young adults (e.g., Meneghetti et al., 2013)

Interestingly, the Age group x Learning group interaction for the landmark locating task showed specific benefits the older SG: only the older adult SG outperformed their peers in the CG, also performing as well as the young adult SG in recalling landmark locations.

These findings indicate that instructing older adults on the use of an effective encoding strategy, such as imagery one, enables them to form accurate mental spatial representations of an environment (e.g., Gyselinck et al., 2007; 2009; Meneghetti et al., 2013), with configured (map-like) features, in terms of representing landmarks and their locations on a layout. These results also suggest that older adults sensitized and guided to use an effective strategy (imagery strategy in our case) can compensate for the age-related decline in their route learning ability.

The benefit for our older participants of practicing with and using an imagery strategy is further substantiated by their self-reported strategy use. The older SG reported following the instructions they had received, not using other types of strategy, and being able to apply the imagery strategy to obtain a detailed mental image of the path seen during the route learning phase. It is noteworthy that some older adults in the CG reported spontaneously using strategies (imagery-based visuospatial strategies, verbal or content-based strategies) when performing the route learning task. That said, previously studies in older adults (e.g., Dunlosky & Herzog, 1998) showed that spontaneous self-reports of having used a potentially effective strategy do not necessarily indicate a real usage of said strategy and a consequently better cognitive performance. Being taught an imagery strategy and reminded to use it during a route learning task did seem to enable our older adult SG to use the strategy appropriately to support their learning and recall of a path, and also to have greater confidence in their ability to complete the task (e.g., Ariel & Moffat, 2018; Carretti et al., 2011). These are only speculations, however. Further studies will be needed to clarify how individuals' ability to monitor and control their use of strategies such as imagery (i.e., so-called metacognitive processes) (e.g., Carretti et al., 2011) relates to their spatial learning performance. This is an issue attracting more and more interest in the spatial domain (Dai, Thomas & Taylor, 2018) also in the field of aging (e.g., Ariel & Moffat, 2018; Mitchell & Cusack, 2018).

It should be noted that there was an Age group x Learning group interaction for the landmark locating, but not for the landmark ordering task. This could be because of the different demands of the tasks. The landmark ordering task involves recalling spatial information (which landmarks came first along the path) from the same first-person perspective (or egocentric view) as was used during the learning phase. The landmark locating task demands a change of viewpoint between the learning and recall phases, from a first-person to a map-like view, which is more resource consuming, especially for older adults (e.g., Muffato et al., 2016; 2018; Yamamoto & De Girolamo, 2012; see Colombo et al., 2017; Lester et al., 2017 for reviews). That managing the spatial information was more effortful in the landmark locating task than in the landmark ordering task used here is also confirmed by the influence of spatial reasoning seen for the former, but not for the latter. Recalling the order of the landmarks thus seemed a feasible task for the older adults (e.g., Barrash, 1994; Cushman et al., 2008; Wilkniss et al., 1997), while locating them accurately proved more difficult.

In this latter case, older adults benefited from using an effective strategy, such as imagery, which facilitated and supported the spatial information processing and spatial inferences needed in the landmark locating task to organize the landmarks in a representation with configured (map-like) features. Using the imagery strategy was thus able to nullify the age-related differences in this type of recall task.

Going against our expectations, young adults did not apparently benefit from being taught an imagery strategy, but this could be because the indoor environments used in our study (a square layout with 10 landmarks arranged along the sides or in the corners) were too easy to learn. Our environments were designed to avoid a floor effect in older adults that might have occurred using more irregular paths and more landmarks (see Meneghetti et al., 2016). This resulted, however, in young adults showing a ceiling effect in both recall tasks already in the CG, so any benefit of being taught to use an imagery strategy could not emerge.

Overall, our findings newly suggest that older adults can still benefit from using an imagery strategy to process spatial information. Using imagery strategy seems able to compensate for age-related impairments in route learning performance, especially in recall tasks that involve actively manipulating previously learned spatial information, such as the location of landmarks along a path.

5. Study 4: Training VSWM on tablets and moving in a controlled setting: preliminary results.

5.1 Rationale and aims of the study

Working memory (WM) training has emerged as a proxy for improving cognitive functioning in aging (e.g., Neely & Nyberg, 2015; Mewborn et al., 2017). So far, there is evidence in aging studies that WM training provide specific training gains. Near transfer effects are commonly, but not always, observed (e.g., Karbach & Verhaeghen, 2014; Teixeira-Santos et al., 2019), however, benefits in terms of far transfer effects still remain controversial (see Constantinidis & Klingberg, 2016; Karbach & Verhaeghen, 2014; Lampit et al., 2014; Melby-Lerväg & Hulme, 2016, 2013; Morrison & Chein, 2011; Schwaighofer, Fischer, & Bühner, 2015; von Bastian & Oberauer, 2013).

Such mixed findings have raised the issue of analyzing which factors might influence WM training efficacy (see Borella, Carbone, Pastore, De Beni, & Carretti, 2017; Zinke et al., 2014; Teixeira-Santos et al., 2019; see Katz, Jones, Shah, Buschkuehl, & Jaeggi, 2016 for a review). Among other factors, the features of the training procedure adopted, such as the training length and the characteristics of the tasks used (e.g., von Bastian & Oberauer, 2013), are worth investigating. The matter of the features of the tasks used for training older adults particularly applies to those, however few, that target VSWM. The lack of consistent benefits promoted by VSWM training (Borella et al., 2014; Buschkuel et al., 2008; Cantarella et al., 2017; Guye & Von Bastian, 2017; Jaeggi et al., 2019; Li et al., 2008; Pergher et al., 2018), along with other explanations, has indeed been suggested to lie in the training modalities adopted (e.g., Borella et al., 2014). Such training programs require older participants to practice - without teaching them strategies - with VSWM complex span tasks or updating tasks using computer-based or tablet-based programs (see Teixeira-Santos et al., 2019), which usually entail processing meaningless stimuli (e.g., remembering the position of shapes or pictures in a matrix) to solve tasks whose demands are less familiar for them and unrelated to their prior knowledge (e.g., Vecchi & Cornoldi, 1999), thus possibly being more complex and difficult to understand. Such aspects might prevent older adults from seeing the training activities as challenging and engaging, limiting, in turn, their motivation and interest towards the training program, and, thus, the training benefits (e.g., Borella et al., 2014).

Considering that individuals have to interact to a great extent with the real-world environment when they use visuo-spatial skills to perform spatial activities in everyday life, it would therefore be of interest to further explore whether using more interactive VSWM tasks would be effective in promoting specific training gains (in tasks similar to the ones trained) as well as transfer effects to other visuo-spatial skills in older adults.

The aim of Study 4 was, therefore, to assess in a sample of healthy older adults whether a VSWM training, which combines practice on VSWM tasks that involve moving in a controlled setting with VSWM tasks administered in a classic modality, i.e., on tablet, promote specific training gains and transfer effects to rotation ability measures. For this purpose, older participants practiced with VSWM tasks similar to the Walking Corsi Test (WalCT; Piccardi et al., 2008; 2013; 2019), entailing moving in a larger-scale controlled setting, as well as with variants of a classic VSWM measure, i.e., the Corsi Blocks Task (Corsi, 1972) on tablet. This choice was made to adopt a training modality which might engage older adult participants to a greater extent, allowing them to interact with the real-world environment in a controlled setting. Moreover, a hybrid training regimen was adopted, combining an adaptive procedure (i.e., the task difficulty was increased if participants were successful at a given level; however, in the case of failure the lowest level was presented) with a constant variation of the task's demands across the training sessions. Such a hybrid procedure is thought to keep the practice novel and challenging, making sure that participants are engaged and motivated toward the proposed activities, thus favoring transfer effects (see Borella, Carretti, Riboldi, & De Beni, 2010; Borella, Carbone, Pastore, De Beni, & Carretti, 2017; Gardner, Strayer, Woltz, & Hill, 2000; Karbach & Kray, 2009).

To assess specific training gains, a tablet version of the backward CBT (adapted from Piccardi et al., 2019), as well as the backward WalCT (Piccardi et al., 2019), were used. Common measures (theoretically related to VSWM) were chosen for measuring transfer effects, according to the conceptually-based continuum of transfer distance proposed by Noack et al. (2009). As for nearest transfer effects, a computerized version of the Pathways Span Task (PST; adapted from Mammarella et al., 2008) was included. This task involves VSWM processes similar to the ones practiced, but the nature of the material and the requirements were different from those of the tasks used in the training. The presence of far transfer effects was determined with the use of two well-proven rotation ability measures, i.e., the Mental Rotations Test (MRT; Vandenberg & Kuse, 1978) and the Object Perspective Test (OPT; Kozhevnikov & Hegarty, 2001). Such transfer measures were chosen for their relationship to VSWM processing resources. Rotation ability has indeed been shown to relate to VSWM processes (Bruyer & Scailquin, 1998; Cornoldi & Mammarella, 2008; Hegarty & Waller, 2005; Hyun & Luck, 2007; Wang & Carr, 2014; Wang, Bolin, Lu & Carr, 2018; Meneghetti et al., 2016b), and VSWM is among those factors explaining age-related effects on rotation performance (e.g., Borella, Meneghetti, Ronconi, & De Beni, 2014; Meneghetti, Borella, Pastore, & De Beni, 2014; Salthouse, Mitchell, Skovronek, & Babcock, 1989; see also Kantler & Jansen, 2016).

In line with the literature on WM training in aging (e.g., Karbach & Verhaeghen, 2014; Texeira-Santos et al., 2019), we expected specific training gains, i.e., an improvement in the criterion tasks. Given that the visuo-spatial tasks chosen to ascertain the presence of transfer effects tap mechanisms related to VSWM processes in older adults, we also expected to find improvements in the PST and in the two rotation ability measures.

5.2 Method

5.2.1 Participants

Eighteen older adults (age range: 65-75 years; 9 females) volunteered for the study. All participants were Italian mother tongue community members recruited through associations in north-eastern Italy, or by word of mouth. The inclusion criteria were: (i) a good state of physical and mental health, and no history of psychiatric or neurological disorders, ascertained by means of a semi-structured interview (De Beni, Borella, Carretti, Marigo, & Nava, 2008); and (ii) a score on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) above the cut-off of 27.

Participants were randomly assigned to a Training Group, involved in the VSWM training, or to an Active Control Group, involved in alternative activities. Three participants in the Training Group and 3 participants in the Active Control Group scored below the cut-off for the Mini-Mental State Examination, so they were excluded from the analyses. The final sample thus comprised 12 participants, seven in the Training Group and five in the Active Control Group. The two groups did not differ in terms of age (Z=-0.25, p=.80), years of education (Z=-0.58, p=.56) and gender distribution (χ_2=.34, p=.56). The demographic characteristics of the final sample by group are given in Table 5.1.

Table 5.1. *Means (M) and standard deviations (SD) of participants' demographic characteristics by group.*

	Training Group N=7 (4 females)		Active Control Group N=5 (3 females)	
	M	*SD*	*M*	*SD*
Age	67.57	1.98	68.00	3.08
Education (in years)	9.29	2.36	8.20	3.27

5.2.2 Materials

5.2.2.1 Specific training gains: criterion tasks

Backward Corsi Blocks Task (adapted from Piccardi et al., 2019). This is an adapted version of the original Corsi Blocks Task (Corsi, 1972) administered on a Hanspree tablet with a 13-inch screen. Nine dark grey squares (3 x 3 cm) are placed at random reproducing the classic configuration of the original task (Corsi, 1972) within an 18 x 25 cm light grey rectangle. Participants are presented sequences of squares of increasing lengths (from 2 to 9 squares) by a black dot that appears on each square of a given sequence for 3 sec (with an interstimulus interval of 500 millisecond). Then, participants have to reproduce the sequence in backward order, indicating the sequence of squares on the tablet screen.

For each sequence, the proportion of squares recalled in their appropriate serial positions was calculated. Moreover, intrusion errors, i.e., the total number of squares that were not present in the sequence and the squares that were repeated, was scored for each sequence. The dependent variables were the mean proportion of squares recalled in their appropriate serial positions and the sum of the intrusion errors made, respectively.

Backward Walking Corsi Test (Piccardi et al., 2019). This larger-scale version of the Corsi Blocks Task (scale 10:1) is set up in a room (5 x 6 m in size), where 9 squares (30 x 30 cm) are placed inside a 3 x 2.5 m carpet arranged on the floor in the same scattered layout as in the original task (Corsi, 1972), and curtains are placed around this configuration to hide all external landmarks (i.e., doors, heaters, windows etc.). The experimenter and participant start from the same point outside the configuration. The experimenter charts sequences of locations which gradually increase in length (from 2 to 9 squares), moving from one location (i.e., a square) to the next in a sequence, and stopping at each location for 2 s. Then participants are asked to repeat the sequence of locations in reverse order as they walk around within the configuration.

For each sequence, the proportion of squares recalled in their appropriate serial positions was calculated. Moreover, intrusion errors, i.e., the total number of squares that were not present in the sequence and the squares that were repeated, was scored for each sequence. The dependent variables were the mean proportion of squares recalled in their appropriate serial positions and the sum of the intrusion errors made, respectively.

For both the two criterion tasks, two parallel versions were prepared and used in a counterbalanced fashion between the pre- and post-test assessment sessions.

5.2.2.2 Transfer effects

Visuo-spatial working memory

Pathways Span Task (PST; adapted from Mammarella et al., 2008, Cornoldi et al., 1999). In this computerized version of the original task, a matrix with a colored cell in the south-west corner is presented on the screen for 4 sec, and then disappears. Participants are asked to mentally imagine following a path on the matrix, starting from the colored cell, based on directions (i.e., forwards, backwards, left, or right) indicated by sequences of arrows (i.e., up, down, left, right) that appear on the screen one at a time for 2 sec each, with an inter-stimulus interval of 1 sec. Finally, a blank matrix appears and participants are asked to indicate the final position reached. The difficulty of the task varies according to the size of the matrix (from 2 x 2 to 6 x 6 cells) and the length of the path (the number of displacements indicated by the arrows). Two parallel versions were prepared and used in a counterbalanced fashion between the the pre- and post-test assessment sessions. The dependent variable was the sum of the final positions correctly recalled (maximum: 9).

Rotation ability

Mental Rotations Test (MRT; Vandenberg & Kuse, 1978). The task consists of assembled cubes with one 3D target figure and four possible matches, and participants have to find the two figures identical to the target, but rotated in space. The original task (the 20-item Vandenberg & Kuse test) was split in two, obtaining two parallel versions, each comprising 10 items to be completed within a time limit of 5 min. The dependent variable was the sum of the items for which the rotated figures were correctly identified (maximum: 10).

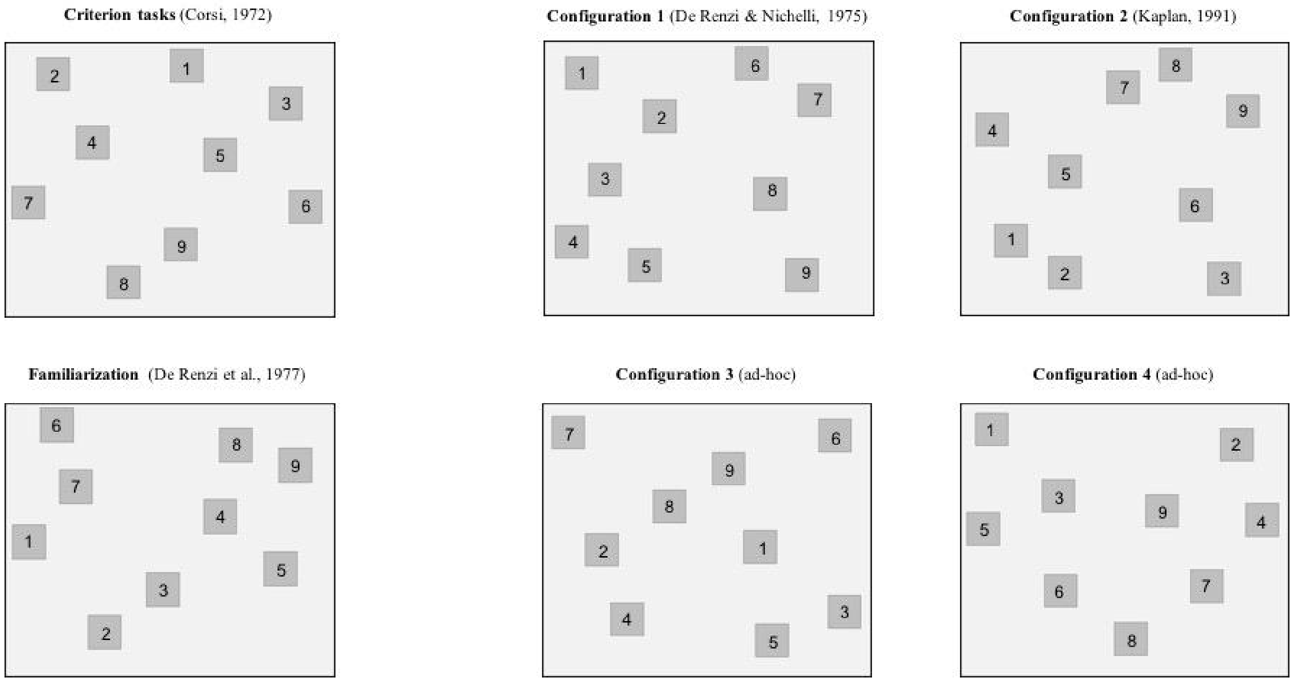
Object Perspective Test (OPT; Kozhevnikov & Hegarty, 2001). The task involves imagining standing alongside one object in a layout of seven objects, facing another, and pointing to a third. The layout remained visible to participants and a circle was used to provide the answer. The original task was split in two, obtaining two parallel versions, each comprising 6 items to be completed within a time limit of 5 min. The absolute angle of error was calculated for each item in degrees of difference between the correct angle and the one indicated by participants. The dependent variable was the mean error in degrees (range: 0°-180°), so higher scores correspond to a worse performance.

5.2.2.3 Materials for the training and control activities

Training tasks for the Training Group

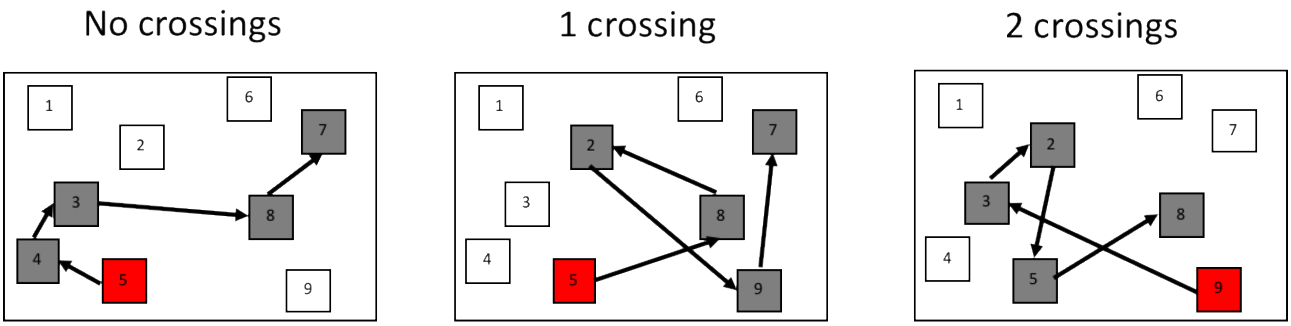
Configurations. Four configurations of 9 squares arranged in a scattered layout different from the configuration used in the criterion tasks were selected (see Figure 5.1). Two were variants of the classic CBT display already used in previous studies (Kaplan, 1991; De Renzi & Nichelli, 1975), while two others were created ad-hoc. In particular, configuration 3 was created moving the squares numbered 7-8-9-6 in the display by Corsi (1972) from the bottom to the top, and squares numbered 2-4-1-5-3 from the top to the bottom (see Figure 5.2). Configuration 4 was created moving the squares numbered 2-4-7 in the display by Corsi (1972) from left to right, and squares numbered 1-3-5-6 from right to left, rearranging the squares numbered 8 and 9 (see Figure 5.1). Another configuration very similar to the one used for the criterion tasks was used across the training sessions to allow participants to familiarize with the tasks' demands before starting the training activities (De Renzi, Faglioli & Previdi, 1977).

Figure 5.1. *Classic configuration used for the criterion tasks, and the configurations selected or created for the familiarization activities and the trained tasks to be used during the training sessions.*



Sequences. For each configuration, 3 forms (A, B, C), each containing 4 sequences for each level of difficulty (from 2 to 7 squares), were created (for a total of 288 sequences, 72 sequences for each configuration). The sequences were balanced across the three forms and the corresponding level of difficulty in terms of starting point (i.e., the sequence could start with a square placed bottom-left, bottom-right, top-left, top-right in the configuration), direction (i.e., the sequence could be arranged with a top-down, bottom-up, left-right or right-left direction within the configuration) and length (i.e., the distance between the squares in a sequence and thus the length covered by the sequence in the configuration was controlled). The complexity of the sequences in terms of number of crossing (i.e., a crossing occurs when any two path segments cross each other) was also balanced (see Figure 5.2 for examples). Form A contained sequences without crossing. Form B contained sequences with 1 crossing starting from level 4. Form C contained two sequences with 1 crossing and 2 sequences with 2 crossing starting from level 4.

Figure 5.2. *Examples of sequences with and without crossings.*


No crossings

1 crossing

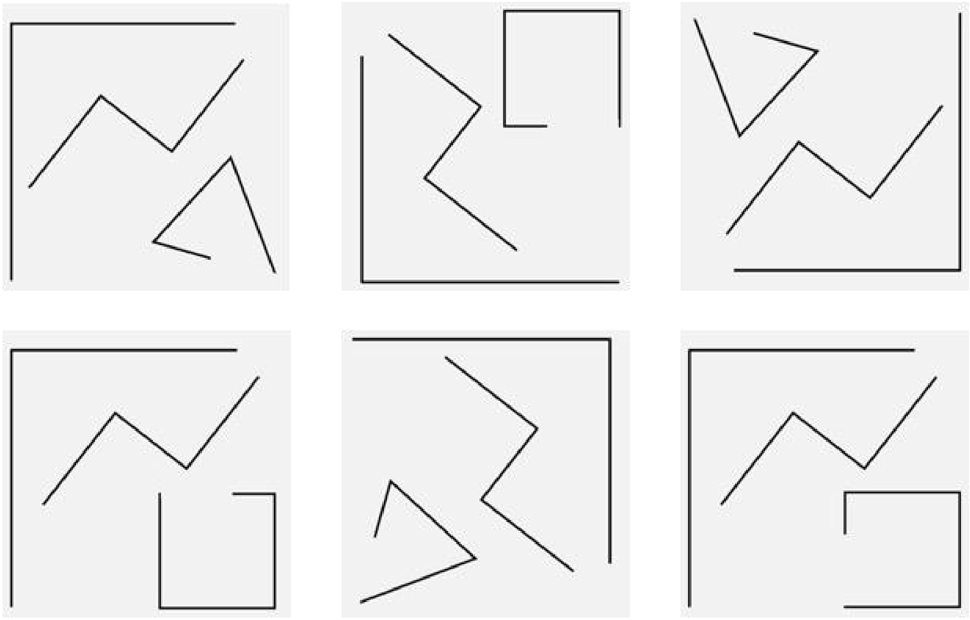
2 crossings

Activities for the active control group

Find the difference task. This task administered on tablet is available at: https://apkpure.com/it/ (Find the differences – 200 levels II). Twelve couple of pictures were used, two for each individual session. Pictures represented either indoor (e.g., a hotel room, a porch, a café) or outdoor (e.g., a lake view, a mountain view, a street with a car) environments, or objects (e.g., a musical instrument, a food tray).

Follow the line task. In this task participants were asked to walk along three lines drawn on the floor following the experimenter's directions (see below for further details). Six different configurations, each one containing three black lines representing a 90° angle (about 4 m long), a dashed line with two 90° angles (about 3 m long), and either an unclosed square (about 4 m long) or an unclosed right triangle (about 3 m long) drawn on a 3 x 3 m carpet were created, one for each individual session (see Figure 5.3).

Figure 5.3. *Configurations of lines used in the follow the line task completed by the active control group.*



5.2.3 Procedure

All participants attended 10 individual sessions. The pre-test, training and post-test sessions engaged participants for two consecutive weeks. The two pre-test sessions (1 and 2) and the two post-test sessions (9 and 10) were completed on two consecutive days, at the start of the first week and at the end of the second week, respectively, and involved all participants in completing a battery of visuo-spatial tasks for the assessment of training benefits. The other 6 sessions, lasting approximately 45 min each, were scheduled on three consecutive days in the second half of the first week (sessions 3-5) and at the start of the second week (sessions 6-8), respectively, with a break at the weekend (see Table 5.2 for the schedule of the activities by group). During these 6 sessions, participants in the Training Group completed the training, while the Active Control Group was involved in alternative activities, as reported below.

Table 5.2. *Schedule of the assessment sessions and activities by group.*

	First week				
	Session 1 (pre-test)	Session 2 (pre-test)	Session 3 (training)	Session 4 (training)	Session 5 (training)
Training Group	1. MMSE 2. CBT (backward) 3. OPT 4. PST	1. WalCT (backward) 2. MRT	Training activities on tablet and moving in a controlled setting	Training activities on tablet and moving in a controlled setting	Training activities on tablet and moving in a controlled setting
Active Control Group			Alternative activities: - find the differences - follow the line	Alternative activities: - follow the line - find the differences	Alternative activities: - find the differences - follow the line
	Second week				
	Session 6 (training)	Session 7 (training)	Session 8 (training)	Session 9 (post-test)	Session 10 (post-test)
Training Group	Training activities on tablet and moving in a controlled setting	Training activities on tablet and moving in a controlled setting	Training activities on tablet and moving in a controlled setting	1. CBT (backward) 2. OPT 3. PST	1. WalCT (backward) 2. MRT
Active Control Group	Alternative activities: - follow the line - find the differences	Alternative activities: - find the differences - follow the line	Alternative activities: - follow the line - find the differences		

5.2.3.1 Training Group activities

Participants practiced with tasks similar to the CBT and the WalCT (see Piccardi et al., 2019): they were presented sequences of squares of increasing length (from 2 to 7 squares) and were asked to recall them, in the following 4 conditions (see Figure 5.4 for pictures of the experimental setting):

i) *Tablet-Tablet task*. The experimenter and the participant were seated in front of a table, on which the tablet was placed on a support inclined approximately 45°, to allow participants to see the whole screen correctly. The sequences of squares were presented on the tablet by a black dot moving in the configuration and stopping on each square for 2 sec, and participants had to reproduce them by tapping each square in the configuration appearing on the tablet screen.

ii) *Walking-Walking task*. The experimenter and the participants stood in front of the carpet where the configuration of squares was displayed. The experimenter showed sequences of squares moving in the configuration and stopping on each square for 2 sec, and participants had to reproduce them walking in the configuration.

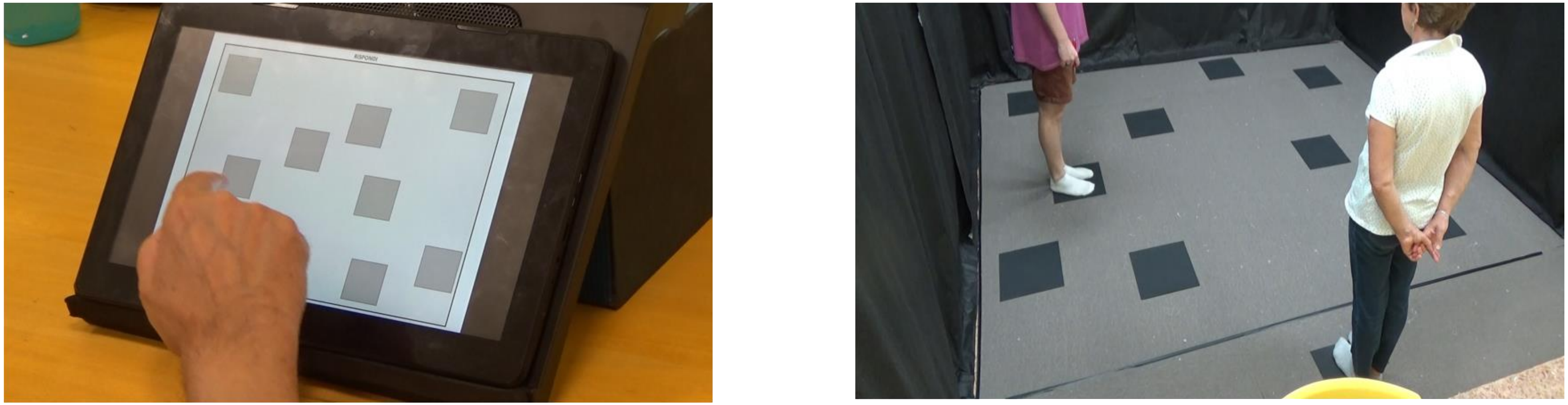
iii) *Tablet-Walking task*. The experimenter and the participant stand in front of a lectern placed in front of the carpet where the configuration of squares was displayed, so that the participant was allowed to see the tablet first and then move in the configuration on the carpet. The sequences of squares were presented on the tablet by a black dot moving in the configuration and stopping on each square for 2 sec, and participants had to reproduce them walking in the corresponding configuration displayed on the carpet.

iv) *Walking-Tablet task*. The experimenter and the participant stood in front of the carpet where the configuration of squares is displayed and with the tablet available on the lectern positioned near the starting position in front of the carpet. The experimenter showed sequences of squares moving in the configuration and stopping on each square for 2 sec, and participants had to reproduce the sequences of squares by tapping each square in the corresponding configuration appearing on the tablet screen.

Figure 5.4. *Experimental setting of the four tasks' conditions for the Combined Training group.*

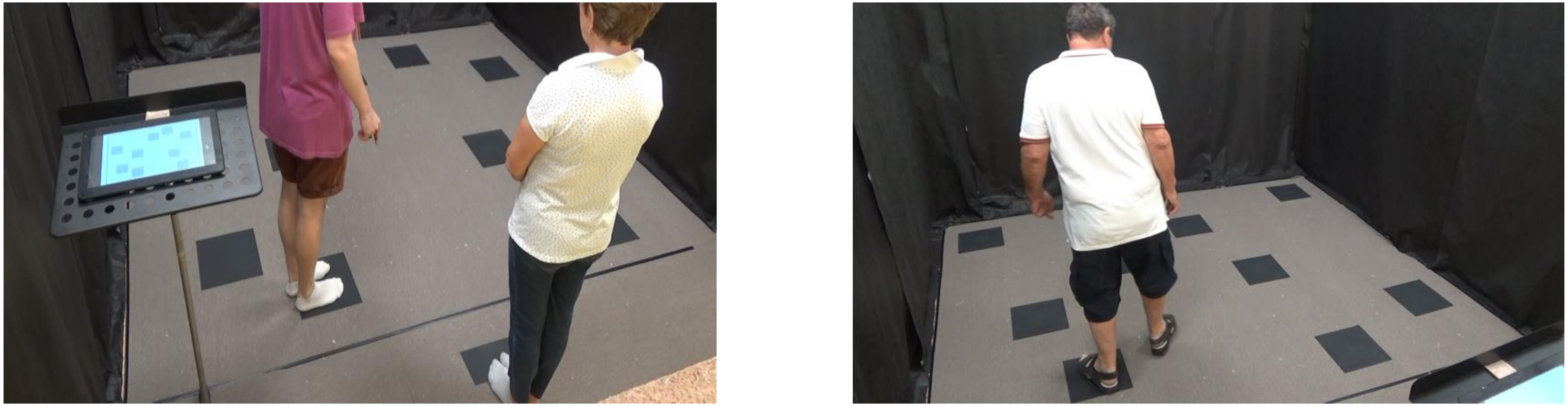
a) Tablet-Tablet task

b) Walking-Walking task



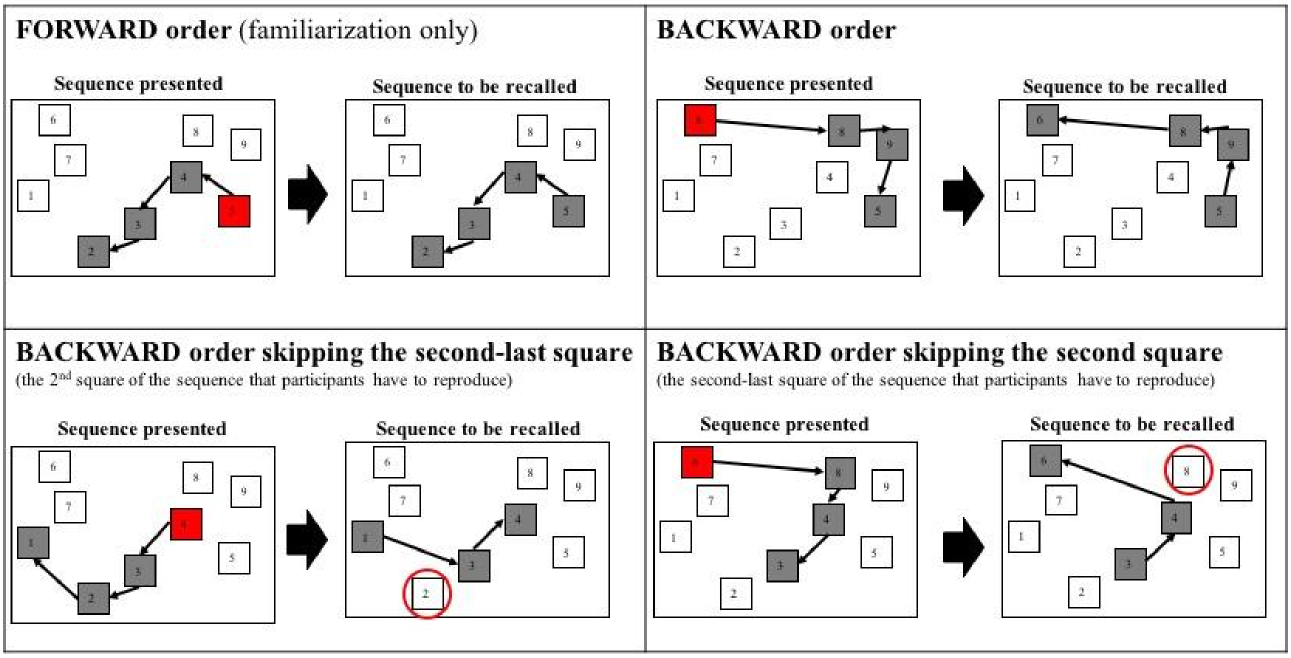
c) Walking-Tablet task

d) Tablet-Walking task



The demands of the tasks varied across the training sessions, so that participants were required to recall a given sequence of squares: i) backward: in the reverse order of presentation (sessions 3-5); ii) backward skipping the second-last square presented, i.e., skipping the second square in the sequence participants themselves had to reproduce in reverse order (sessions 6-8); iii) backward skipping the second square presented, i.e., skipping the second-last square in the sequence participants themselves had to reproduce in reverse order (sessions 6-8) (see Figure 5.5 for an example).

Figure 5.5. *Examples of training tasks' demands.*



Sessions 3 to 7 were divided into two parts, with a 5 min break in between them. In the first part of each session, participants practiced in one of the four abovementioned conditions and repeated the task twice, while in the second part they practiced in another one of the four abovementioned condition, again repeating the task twice (see Table 5.3 for details). The configuration used changed each time the task was proposed to participants, so that in all the training sessions they always practiced with all 4 configurations, presented in a randomized order across the training sessions.

The difficulty of the tasks was adaptive: for each level of difficulty (from 2 to 7 in session 3 to 5 and from level 3 to 7 in sessions 6 and 7) if the participant reproduced 2 out of 4 sequences correctly for a given level, the task increased in difficulty; if the participant failed to reproduce 2 out of 4 sequences correctly at a given level, the task ended and the participant was administered again with the task starting from the easiest level (from level 2 in session 3 to 5 and from level 3 in sessions in sessions 6 and 7).

In sessions 3 to 5 participants had to recall the sequences in backward order only. In session 6 the task requests were to recall the sequences in backward order skipping the second-last square, while in session 7 participants had to recall the sequences in backward order by skipping the second-last square or in backward order skipping the second square, alternately across the four times they practiced with the trained tasks.

Also, session 8 was divided into two parts, with a 5 min break in between them. However, participants in this session practiced only twice and were required to complete the whole tasks from the easiest to the hardest level of difficulty (from 3 to 7), regardless of their performance. Two sequences of stimuli were presented for each level of difficulty. When participants practiced the first time, they were required to perform one sequence of each level of difficulty in the Tablet-Walking condition and the second one in the Tablet-Tablet condition. The second time participants performed one sequence of each level of difficulty in the Walking-Walking condition and the second one in the Walking-Tablet condition. Participants had to recall the sequences always in backward order skipping the second square.

Participants practiced with easier sequences (i.e., using form A) in session 3 and then the complexity of the sequences presented varied (i.e., form B in sessions 4, 6 and 8 and form C in sessions 5 and 7).

Table 5.3. *Training Group activities during the training sessions.*

Session		Timing	Task's condition	Task's demand	Configuration	Sequences' features	Tasks' difficulty
3	First Part	15/20 min	TABLET-TABLET task (twice)	recall in BACKWARD order	1 and 2	Form A	Adaptive
	Second Part	15/20 min	WALKING-WALKING task (twice)		3 and 4		
4	First Part	15/20 min	WALKING-WALKING task (twice)	recall in BACKWARD order	2 and 3	Form B	Adaptive
	Second Part	15/20 min	TABLET-WALKING task (twice)		4 and 1		
5	First Part	15/20 min	TABLET-WALKING task (twice)	recall in BACKWARD order	3 and 4	Form C	Adaptive
	Second Part	15/20 min	WALKING-TABLET task (twice)		1 and 2		
6	First Part	15/20 min	WALKING-WALKING task (twice)	recall in BACKWARD order skipping the second-last square	4 and 1	Form B	Adaptive
	Second Part	15/20 min	WALKING-TABLET task (twice)		3 and 2		
7	First Part	15/20 min	TABLET-WALKING task (twice)	First time: recall in BACKWARD order skipping the second-last square Second time: recall in BACKWARD order skipping the second square	1 and 2	Form C	Adaptive
	Second Part	15/20 min	TABLET-TABLET task (twice)		3 and 4		
8	First Part	15/20 min	TABLET-WALKING and TABLET-TABLET task	recall in BACKWARD order skipping the second square	1	Form B	Non adaptive
	Second Part	15/20 min	WALKING-WALKING and WALKING-TABLET task		2		

5.2.3.3 Active Control Group activities

During each of the 6 individual sessions, participants in the Active Control Group performed both the find the difference task and the follow the line task, which were presented in a counterbalanced order across the 6 sessions.

As for the find the difference task, participants had to look at pairs of pictures presented on the tablet screen and find 10 differences between them, i.e., tapping on the tablet screen in the corresponding part of the image in which there was a different element or detail between the two photos. Two pairs of pictures were completed during each training session, with a time constraint of 10 min for each one.

As for the follow the line task, the experimenter and the participant stood in front of the carpet where the configuration of lines was displayed and had the tablet, on which the same configuration of lines was reproduced, available on the lectern positioned near the starting position in front of the carpet. Participants were asked to walk 3 lines (in a counterbalanced fashion across training sessions), as follows: i) *Walking-Walking task*: the experimenter walked one line and then the participant was invited to reproduce the same line by walking it; ii) *Tablet-Walking task*: the experimenter indicated a second line on the tablet and invited the participant to walk it on the carpet; ii) *Walking-Tablet task*: the experimenter indicated a third line on the carpet and invited the participant to walk it; then, the participant had to indicate the line walked by tapping it on the configuration presented on the tablet screen (see Figure 5.6 for examples of the experimental setting). Such activities proposed to the Active Control Group mirrored the four conditions in which the training activities were administered to the Training Group. Thus, the same amount of interaction with the experimenter as well as with the controlled setting was also provided to controls, however the activities proposed were not meant to load VSWM processing resources.

Figure 5.6. *Experimental settings for the active control group.*

Find the differences task

Follow the lines task

5.3 Results

Descriptive statistics for the measures of interest at pre-test and post-test by group are reported in Table 5.4.

Given the small sample size, to examine specific training gains and transfer effects, Cohen's (1988) *d* - expressing the effect size of the comparisons between pre-test and post-test - were calculated for each measure of interest for both the Training and the Active Control groups. Values were corrected using the Hedges and Olkin (1985) correction factor in view of the small sample bias.

As for the Training group, large effect sizes were found for the accuracy and intrusions errors in the backward WalCT and for the PST. Medium effect sizes were found for the accuracy in the backward CBT, while small-to-medium effect sizes emerged for the intrusion errors in the backward CBT, for the OPT and for the MRT, however, in this latter case it suggests a decrease in performance between the pre-test and the post-test.

As for the Active Control Group, small-to-negligible effect sizes were found for both the accuracy and the intrusions errors in the backward WalCT, for the intrusions errors in the backward CBT, and for the MRT. Medium effect sizes were found for the accuracy in the backward CBT and for the OPT, revealing an improvement from pre-test to post-test in both the two tasks.

Table 5.4. *Descriptive statistics for the measures of interest at pre-test and post-test and Cohen's d of the comparisons between pre-test and post-test by group.*

	Training Group (N=7)					Active Control Group (N=5)				
	Pre-test		Post-test			Pre-test		Post-test		
	M	*SD*	*M*	*SD*	*d*	*M*	*SD*	*M*	*SD*	*d*
CBT (backward) - accuracy	81.58	5.09	85.11	7.27	0.52	80.72	5.70	84.40	6.74	0.53
CBT (backward) - errors	2.00	0.82	1.43	1.81	-0.37	2.40	1.52	2.40	0.89	0.00
WalCT (backward) - accuracy	72.93	8.59	83.02	3.95	1.39	76.04	7.69	76.89	8.64	0.09
WalCT (backward) - errors	4.43	1.51	3.14	1.57	-0.77	5.00	2.00	5.20	1.64	0.10
PST	5.14	1.35	6.29	0.49	1.05	4.40	1.67	5.20	1.30	0.48
MRT	3.00	2.08	2.17	1.46	-0.42	2.00	1.87	1.80	2.49	-0.08
OPT	79.43	23.88	69.17	24.02	-0.40	99.77	6.41	87.33	24.05	-0.63

Note. CBT: Corsi Blocks Task; WalCT: Walking Corsi Test, PST: Pathways Span Task; MRT: Mental Rotations Test; OPT: Object Perspective Test.

5.4 Discussion

The aim of this study was to ascertain in a sample of healthy older adults whether training VSWM using more interactive VSWM tasks would be effective in promoting specific training gains (in VSWM tasks similar to the ones trained) as well as transfer effects to other visuo-spatial skills in older adults.

To this aim, older participants were randomly assigned either to a Training Group, which was involved in the VSWM training, or to an Active Control Group, involved in alternative activities.

As for the Training Group, in order to promote participants' engagement towards the training activities: i) we combined the practice with VSWM tasks involving moving in a controlled setting and VSWM tasks yielded in a classic modality, i.e., on tablet; and ii) we adopted an hybrid training regimen, combining an adaptive procedure with a constant variation of the task's demands (i.e., changing the conditions in which participants practiced on the trained tasks, as well as the features of the stimuli presented, both in terms of display and complexity), to keep the practice novel, challenging and motivating, in order to favor transfer effects (see Borella et al., 2010; 2017; Gardner et al., 2000; Karbach & Kray, 2009).

It is worth stressing that this is the first aging study that has attempted to design a VSWM training program which also adopts, unlike previous studies (Borella et al., 2014; Buschkuel et al., 2008; Cantarella et al., 2017; Guye & Von Bastian, 2017; Jaeggi et al., 2019; Li et al., 2008; Pergher et al., 2018), more interactive training tasks involving moving about in the "real-world" environment - though in a controlled setting.

Concerning the Active Control Group, participants were involved in alternative activities that attempted to mirror the ones of the training program in terms of the amount of interaction between participants and both the experimenter and the controlled setting, though they were thought not to load on VSWM processing resources, being low-intensive activities.

Although the sample size so far is small, some considerations can be drawn from the preliminary results. Results highlighted that the Training Group, but not the Active Control Group, showed an improvement, both in terms of accuracy and lower rates of intrusion errors, in the backward WalCT from pre-test to post-test. Such a pattern of findings, in line with our expectations and with previous evidence from working memory training studies in aging (e.g., Karbach & Verhaeghen, 2014; Texeira-Santos et al., 2019), suggests that the training prompted specific training gains in a task that was very similar to the ones trained.

No clear conclusions can be drawn from the current pattern of findings for the other measures of interest, however. A larger sample size would allow further investigation as to whether, and to what extent, the benefits gained by the Training Group *vis-à-vis* the ones shown by the Active Control Group are not due to test-retest effects or individual differences.

Overall, the results from this study, though preliminary, suggested that the use of more interactive VSWM training procedures is feasible in terms of being applied to older adults, leading to the promotion of at least specific training gains. Further research is needed to confirm the efficacy of the VSWM training program implemented here, especially in relation to transfer effects concerning visuo-spatial skills that were not directly trained, as well as the maintenance of any training benefits in the long-term.

6. General discussion and conclusions

6.1 Summary of the findings and their implications

The general aims of the present dissertation were to further explore the age-related differences between young and older adults' spatial abilities (environmental and visuo-spatial), investigating, through four studies: i) the role of individual characteristics (i.e., personality) in influencing young and older adults' visuo-spatial abilities and inclinations; ii) the use of new interactive tasks to assess visuo-spatial abilities (i.e., visuo-spatial working memory [VSWM]); iii) the adoption or the development of cognitive procedures to support/improve both spatial (route) learning skills and visuo-spatial abilities in aging.

Study 1 focused on the role of personality characteristics in influencing individuals' visuo-spatial factors in young and older adults. They refer to those objective visuo-spatial abilities (assessed here by means of rotation ability and VSWM tasks) and self-assessed visuo-spatial inclinations (assessed here with spatial self-reports on pleasure in exploring places and spatial anxiety), known to have a role in supporting everyday spatial navigation and environment learning skills across the adult lifespan (e.g., Meneghetti et al., 2014; 2016; Muffato et al., 2016; 2018; 2019; see Klencklen et al., 2012; Lester et al., 2017; for reviews). The choice of focusing on personality, among other individual characteristics, was prompted by the broad evidence of an association between personality and cognitive functioning (in young adults: Ackerman, 2018; in older adults: Curtis et al., 2015 for reviews), with only a few previous studies exploring its relationship with individuals' visuo-spatial factors (in young adults: Condon et al., 2015; Pazzaglia et al., 2017; in older adults: Schaie et al., 2004). Adopting the Big Five model (Goldber, 1993) as a framework, the major personality traits were considered as well as their narrower facets, to better capture the relationship between personality and both objective and self-reported visuo-spatial skills (see Curtis et al., 2015). The results confirmed, in line with our expectations and previous evidence (e.g., Borella et al., 2014; De Beni et al., 2014), that age negatively predicted the variance in objective visuo-spatial tasks, but not in self-assessed visuo-spatial inclinations, while only the latter were slightly influenced by gender (in favor of men) (e.g., De Beni et al., 2014; Linn & Petersen, 1985; Hegarty & Waller, 2005; Lawton, 1994). Further, in line with the few previous findings (in young adults: Condon et al., 2015; Pazzaglia et al., 2017; in older adults: Schaie et al., 2004), and as expected, both objective visuo-spatial abilities (albeit modestly) and self-assessed visuo-spatial inclinations were predicted by higher Conscientiousness. The latter were also predicted by higher Emotional Stability. Finally, a better objective visuo-spatial performance was explained (again modestly) by lower Dynamism and Politeness, and higher Emotion Control, while higher Perseverance, Emotion Control and Cooperativeness explained a moderate part of the variance in the positive self-assessed visuo-spatial inclinations.

Such a pattern of findings allows to shed more light on the association between personality and individuals' visuo-spatial factors, indicating that - beyond age and gender - some personality traits and facets predict self-assessed visuo-spatial inclinations to a larger extent than objective visuo-spatial performance. They also underscore the need to take into account not only personality traits but also their narrower facets to better clarify the association between personality and cognition (or spatial cognition in the present study) when such aspects are jointly assessed, especially necessary in aging studies (e.g., Curtis et al., 2015).

Study 2 addressed a second important issue related to the assessment of VSWM, a core mechanism sensitive to age-related decline (e.g., Mammarella et al., 2013) and among those factors explaining age-related effects on high-order visuo-spatial abilities, such as rotation (Borella et al., 2014; Hegarty & Waller, 2005; Meneghetti et al., 2014), with implications for individuals' ability to engage several everyday spatial activities successfully (see Klencklen et al., 2012). Classic measures of VSWM require participants to manage visuo-spatial stimuli presented on sheets of paper, wooden boards or computer screens (e.g. Hegarty et al., 2006). VSWM was assessed here both in young adults and newly in older adults using an extended version of a classic VSWM measure, i.e., the backward Corsi Blocks Task (CBT; Corsi, 1972), called the backward Walking Corsi Test (WalCT; Piccardi et al., 2019), which involves recalling sequences of spatial locations while moving around in a controlled setting. The study aimed to thoroughly explore the relationship between this new VSWM task and classic VSWM measures, to ascertain its concurrent validity, and its association with self-assessed visuo-spatial attitudes to environment-related tasks. A further aim was to explore the specific contribution of the backward WalCT, beyond that of the classic CBT, in mediating age-related effects on rotation ability was analyzed using a structural equation model. First, as expected and in line with the literature (e.g., Borella et al., 2014; De Beni et al., 2014; Mammarella et al., 2013; Techetin et al., 2014), the results confirmed the age-related differences in favor of young adults in the backward WalCT, and in all the other visuo-spatial measures used as well. Then, the two age groups did not differ in their spatial self-assessments, in line with previous findings (Borella et al., 2014; De Beni et al., 2014). Further, the results showed medium-to-large correlations between the backward WalCT and classic VSWM measures, but, in line with previous studies (see, for example, Muffato et al., 2017; Meneghetti et al., 2014), there were no significant correlations between this task - as for the other classic VSWM measures - and visuo-spatial self-assessments. In line with expectations and previous evidence (e.g., Briggs et al., 1999; Borella et al., 2014; Kantler & Jansen, 2016; Raz et al., 1999), the results of the structural equation model showed a direct age-related effect on VSWM, as measured with the backward WalCT and the backward CBT, and rotation ability. VSWM was found to mediate the age-related effects on rotation ability.

These findings highlight that the backward WalCT can be considered as another VSWM task which can be used to assess VSWM in older adults. It indeed demands processing resources and attentional control (Brown, 2016) in common with complex VSWM span tasks (see Cornoldi & Vecchi, 2003; Fiore et al., 2011; Mammarella et al., 2013), that are known to decline with aging (e.g., Borella et al., 2008). Such a VSWM measure, in common with other VSWM tasks, explain age-related effects on complex visuo-spatial abilities, such as rotation. Further, it could be considered not only feasible to administer but – importantly - an engaging task, due to the fact that it involves participants interacting to a greater extent with the real-world environment - though in a controlled setting - and has requests that are more likely to seem concrete and meaningful (compared with classic VSWM measures), to older adults in particular.

An overview of the content and main results of Studies 1 and 2 is presented in Table 6.1.

Table 6.1. *Overview of the content and main results of Studies 1 and 2.*

General aims	Sample	Outcome measures	Mail results		
Study 1: Exploring the association between personality (traits and facets) and individuals' visuo-spatial factors.	70 YA (age range: 18-35 years) 70 healthy OA (age range: 65-75 years)	*Personality*: the BFQ-60 *Objective visuo-spatial abilities*: the backward CBT; the PST; the Puzzle; the sMRT; the sOPT *Self-assessed visuo-spatial inclinations*: the AtOT and SA scales	The role of:	Objective visuo-spatial abilities	Self-assessed visuo-spatial inclinations
			Age	✓ (YA>OA)	
			Gender		✓ (Males>Females)
			Personality traits	✓ (Weak effect) (+Conscientiousness)	✓ (Moderate effect) (+Conscientiousness; +Emotional Stability)
			Personality facets	✓ (Weak effect) (+Emotion Control; -Politeness; -Dynamism)	✓ (Moderate effect) (+Emotion Control; +Scrupulousness; +Cooperativeness)
Study 2: Using a new VSWM measure, i.e., the backward WalCT, to explain age-related effects on rotation ability.	70 YA (age range: 18-35 years) 56 healthy OA (age range: 65-75 years)	*Objective visuo-spatial abilities*: -VSWM: the backward WalCT; the backward CBT; the PST; the Puzzle -Rotation ability: the sMRT; the sOPT *Self-assessed visuo-spatial inclinations*: the AtOT and SA scales		Backward WalCT	
			The role of Age:	✓ (YA>OA)	
			Correlations with: -classic VSWM tasks	✓ (Medium-to-large)	
			-spatial self-assessments		
			Age had a direct effect on rotation ability, mediated by VSWM - as measured by means of the backward WalCT and the backward CBT. VSWM mediated the age-related effects on rotation ability.		

Note. VSWM: visuo-spatial working memory; YA: young adults; OA: older adults; BFQ-60: the Big Five Questionnaire-60; CBT: Corsi Blocks Task; WalCT: Walking Corsi Test; PST: Pathways Span Task; Puzzle: Puzzle test; sMRT: short Mental Rotation Test; sOPT: short Object Perspective Test; AtOT: Attitude to Orientation Task scale; SA: Spatial Anxiety scale.

Concerning Studies 3 and 4, these latter studies addressed the issue of supporting/improving older adults' spatial abilities. Indeed, a growing body of research on aging attempts to explore the benefits of cognitive techniques/procedures for supporting older adults' cognitive functioning, to promote their active aging and a better quality of life (e.g., Herzog et al., 2008; Mewborn et al., 2017; Reichman et al., 2010). Surprisingly, despite the well-proven age-related changes that older adults experience in their spatial abilities, which might affect their autonomy and independent living, there is a paucity of studies focusing on how to support/improve them in aging. Hence the need to further explore this issue by taking into account two main approaches, i.e., a strategy-based approach and a process-based approach.

A strategy-based procedure was used in Study 3 to explore how to support older adults' spatial (route) learning abilities. Taking into account previous studies concerning young adults only (e.g., Gyselinck et al., 2007; 2009; Meneghetti et al., 2013), this study aimed to further ascertain the benefit of using an imagery strategy to support route learning in young, and, for the first time here and as a novel aspect, in older adults. Results showed, as expected and in line with the literature (see Klencken et al., 2012; Lester et al., 2017; Moffat, 2009 for reviews), that young adults recalled the order and location of landmarks better than older adults. Further, in line with our expectations and previous evidence (e.g., in young adults: Meneghetti et al., 2013; in older adults: Craik & Rose, 2012; Gross et al., 2012; Herzog et al., 2008; Verhaeghen et al., 1992), the strategy groups outperformed the control groups, regardless of age. As expected for older adults and in line with previous evidence (see Craik & Rose, 2012), the Age group x Learning group interaction was found to be significant, though only for the landmark locating task, with the younger control group performing better than the older control one, while the older strategy group proved as good at recalling landmark locations as the younger strategy one. Further, it was only among the older adults that the strategy group outperformed the control group.

Such a pattern of findings suggests that instructing older adults on the use of an effective encoding strategy, such as imagery one, allows them to form accurate mental spatial representations of an environment. In particular, being taught and advised to use imagery strategy during the route learning task enabled our older adults to use the strategy appropriately to support their learning and recall of the path, especially facilitating and supporting the spatial information processing and spatial inferences needed in the landmark locating task to organize the spatial information acquired in a representation with configured (map-like) features. Importantly, these results also suggest that older adults who are sensitized and guided to use an effective strategy (imagery strategy in our case) can compensate for the age-related decline in their route learning ability.

Study 4 adopted a process-based training approach to explore, for the first time in a sample of healthy older adults, whether using more interactive VSWM tasks to train VSWM – given its well-known age related-decline (e.g., Mammarella et al., 2013) and its involvement in high-order visuo-spatial skills (e.g., Borella et al., 2014; Meneghetti et al., 2014; Salthouse et al., 1989; see also Kantler & Jansen, 2016) – would promote specific training gains and transfer effects to untrained rotation ability measures. Unlike classic VSWM training programs (Borella et al., 2014; Buschkuel et al., 2008; Cantarella et al., 2017; Guye & Von Bastian, 2017; Li et al., 2008; Pergher et al., 2018), the training procedure developed and used here involved the trained participants in practicing both with VSWM tasks involving moving in a larger-scale controlled setting (similar to the WalCT; Piccardi et al., 2008; 2013; 2019), and VSWM tasks yielded in a classic tablet-based modality (similar to the CBT; Corsi, 1972), in order to make the practice more interactive and possibly engaging, thus favoring training benefits.

The preliminary results, in line with the literature on WM training studies in aging (e.g., Karbach & Verhaeghen, 2014; Texeira-Santos et al., 2019) and with our expectations, showed that the VSWM training program promoted short-term specific training gains in one of the criterion tasks in the Training Group - but not in the Active Control Group, i.e., the backward WalCT. No clear conclusions in relation to the other outcome measures considered can be drawn yet, however, the pattern of findings is promising. It is worth highlighting that this is an ongoing study, and a larger sample is now going to be involved to confirm the efficacy of the VSWM training program developed here, also in relation to transfer effects to visuo-spatial skills not directly trained, as well as to any maintenance of training benefits in the long-term.

An overview of the content and main results of Studies 3 and 4 is presented in Table 6.

Table 6.2. *Overview of the content and main results of Studies 3 and 4.*

General aims	Sample	Outcome measures	Mail results				
Study 3: Exploring the beneficial effect of practicing and using an imagery strategy to support spatial (route) learning.	40 YA (age range: 18-35 years) 40 healthy OA (age range: 65-75 years)	Recall tasks: -landmarks ordering task -landmarks locating task		Landmarks ordering task		Landmarks locating task	
			Age group	✓ (YA>OA)		✓ (YA>OA)	
			Learning group	✓ (SG>CG)		✓ (SG>CG)	
			Age group X Learning group			✓ (-The YA CG > the OA CG; -The OA SG = the YA SG; -Only among YA, SG > CG)	
Study 4: Training VSWM combining the practice with VSWM tasks entailing a greater amount of interaction with the real-world environment, i.e., to move around in a controlled setting, and VSWM tasks yielded in a classic modality, i.e., on tablet.	12 healthy OA (age range: 65-75 years)	*Specific training gains:* the backward CBT; the backward WalCT *Nearest-transfer effects:* the PST *Far transfer effects:* the MRT; the OPT		Specific training gains		Transfer effects	
			Effect sizes (pre- and post-test difference)	Large	Medium	Large	Medium
			Training Group	the backward WalCT	the backward CBT (accuracy)	the PST	the MRT and the OPT
			Active Control Group		the backward CBT (accuracy)		the PST, the MRT and the OPT

Note. VSWM: visuo-spatial working memory; YA: young adults; OA: older adults; SG: strategy group; CG: control group; CBT: Corsi Blocks Task; WalCT: Walking Corsi Test; PST: Pathways Span Task; MRT: Mental Rotations Test; OPT: Object Perspective Test.

Overall, the results from Studies 1 and 2 confirm that objective visuo-spatial abilities, on the one hand, i.e., high-order visuo-spatial abilities such as rotation and processing resources such as VSWM, and self-reported visuo-spatial inclinations, on the other hand, constitute two of the individuals' visuo-spatial factors, according to the model proposed by Hegarty et al. (2006). Such visuo-spatial factors show, in line with the literature (e.g., Borella et al., 2014; De Beni et al., 2014; Mammarella et al., 2013; Vojer et al., 2014 for a meta-analysis), different age-related changes: older adults showed a worse performance, compared with young adults, in the objective visuo-spatial measures considered here, while no age-related differences between young and older adults were found for the self-assessed visuo-spatial inclinations. Furthermore, the findings from these two studies have important implications in relation to the assessment of age-related and individual differences in visuo-spatial skills, both in experimental and, potentially, in clinical settings: the results from Study 1 point to the importance of considering personality among the individual characteristics that influence young and older adults' visuo-spatial abilities and inclinations, and the results from Study 2 suggest that the backward WalCT configures among the visuo-spatial measures particularly suitable for assessing VSWM in different age groups, and especially in older adults.

The pattern of findings from Studies 3 and 4 supports previous suggestions on the malleability of spatial abilities in aging (see Lester et al., 2017; Meneghetti et al., 2018; Borella et al., 2014; Buschkuel et al., 2008; Cantarella et al., 2017; Guye & Von Bastian, 2017; Jaeggi et al., 2019; Li et al., 2008; Pergher et al., 2018) and have implications for the implementation and adoption of effective procedures to support/improve them in aging. As for the results from Study 3, they suggest that practicing and using imagery strategy help older adults to compensate for the age-related decline in route learning ability, especially in spatial recall tasks demanding the active manipulation of spatial information learnt, such as locating landmarks previously encountered while navigating a path. Concerning Study 4, the preliminary results found suggest, for the first time, that the use of a more interactive VSWM training procedure seems feasible to use with older adults, leading, in the least, to promote specific training gains. Such findings offer insight and open new directions toward the development and the adoption of more structured strategy-based procedures, as well as of process-based cognitive interventions to support/improve older adults' spatial abilities, essential for their mastery of the environment.

6.2 Limitations and suggestions for future research

Despite these interesting findings, some issues emerge when we consider the limitations of the present studies.

First, future studies should expand and confirm our results on the association between personality and spatial cognition, also across the adult life span, using: i) a broad battery of visuo-spatial tasks that tap not only rotation and VSWM abilities (as done here), but also other visuo-spatial skills crucial to daily living, such as spatial visualization and spatial perception (Linn & Petersen, 1975), ii) other spatial self-reports, such as self-assessed sense of direction, or preferred spatial strategies or navigation aids (see Condon et al., 2015; Pazzaglia et al., 2018); and iii) tasks that demand large-scale abilities (such as route learning, spatial orientation) (e.g., Bryant, 1982; Pazzaglia et al., 2018), not considered here.

The features and processes involved in the backward WalCT, newly used here with older adults, deserve further investigation too. In particular, future studies should include measures for assessing visuomotor and vestibular functions (e.g., gait speed and walking time, balance and motor functioning), which are also implicated when individuals move about in the environment, such as in this task (e.g., Moffat, 2009; Lester et al., 2017; Wolbers & Hegarty, 2010) and sensitive to aging (Lester et al, 2017), in order to shed more light on the involvement of such processes in backward WalCT performance.

Concerning the improvement of spatial abilities, future studies should replicate our findings on the benefit of instructing older adults on the use of imagery strategy to perform route learning tasks including other age-sensitive spatial recall tasks, such as pointing to locations that are not visible, estimating distances, or finding shortcuts (e.g., Muffato et al., 2016; 2018; 2019).

As for the VSWM training, a larger sample size would determine whether any training benefit gained by the Training group vis-à-vis the ones for the Active Control Group are not due to test-retest effects, or individual differences, thus confirming the VSWM training efficacy in providing specific training gains and transfer effects. A follow-up assessment would also highlight whether any training benefit would be maintained. Further, it would be of interest to compare the VSWM training procedure developed here with VSWM training programs adopting the same materials, organized in the same way, though administered exclusively in a classic tablet-based modality, or in a fully interactive modality, respectively. Such a comparison might allow us to further understand which could be the best and most effective procedure to train VSWM in older adults (in terms of the features of the training tasks used).

Finally, some of the issues addressed in this dissertation are also worth investigating in relation to pathological aging, since visuo-spatial dysfunctions are known to be among the first clinical signs of Alzheimers' Disease (AD) (e.g., Salimi, Irish, Foxe, Hodges, & Piguet, 2017). Given the influence of personality traits and facets on individuals' visuo-spatial factors suggested by our results, a joint assessment of personality and cognitive functioning could indeed have important implications for the detection of potential adverse effects on visuo-spatial abilities and inclinations in older adults, especially those who are frail (e.g., Caselli et al., 2018; Low, Harrison, & Lackersteen, 2013). Slight changes in personality traits (including an increase in neuroticism) have indeed been shown to occur in presymptomatic AD, and to characterize the transition from mild cognitive impairment to frank dementia, fostering its negative behavioral and cognitive outcomes (e.g., Caselli et al., 2018). Concerning the assessment of VSWM, the backward WalCT might be suitable for differentiating between normal and pathological aging in the early stages of cognitive decline (mild cognitive impairment) (see Boccia et al., 2019), or in preclinical stages of AD, by capturing those visuo-spatial dysfunctions that are the earliest signs and a potential cognitive marker of AD (Salimi et al., 2017). Finally, further studies might focus also on older adults with mild cognitive impairments, to see if training to use the imagery strategy can counteract or delay the related decline in their route learning ability (see Lithfous, Dufour & Deprés, 2013 for a review), and consequent loss of autonomy.

6.3 Conclusions

In conclusion, the present dissertation sheds light on the individual and age-related differences influencing individuals' visuo-spatial factors, showing that, in particular, personality plays a part in explaining objective visuo-spatial abilities and self-reported visuo-spatial inclinations' performance in young and older adults. It also highlights the feasibility of using more interactive and engaging visuo-spatial measures for the assessment of visuo-spatial skills, especially for older adults. Finally, it advances our understanding on the malleability of spatial abilities in aging, suggesting that practicing and using the imagery strategy support older adults' environment learning skills. The use of more interactive tasks to train VSWM in healthy older adults also seems feasible, resulting in providing at least specific training gains. Although further research is needed, such findings would guide future studies aiming to comprehensively assess the age-related and individual differences in visuo-spatial skills, as well as to develop effective strategy-based or process-based cognitive procedures/interventions to support and improve older adults' spatial abilities, with the goal of promoting their autonomy and independent living and, thus, active aging.

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