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The role of spatial abilities and self-assessments in cardinal point orientation across the lifespan

Chiara Meneghetti [a],*, Erika Borella [a],*, Massimiliano Pastore [b], Rossana De Beni [a]

[a] *Department of General Psychology, University of Padova, Italy*
[b] *Department of Developmental and Social Psychology, University of Padova, Italy*

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ABSTRACT

The aim of this study was to investigate the relationship between age, spatial abilities, spatial self-assessments, working memory (WM) and environment knowledge, through an orientation task based on pointing in cardinal directions, across the adult lifespan using the structural equation modeling (SEM) approach. A group of 450 people from 20 to 91 years old was asked to point in the direction of cardinal points and to complete a set of spatial tasks, spatial questionnaires and WM measures. Results showed that, while spatial abilities and positive self-assessments mediated the influence of age on the ability to identify cardinal points, WM accounted for the age-related variance in spatial abilities and positive self-assessments. Age also had a direct influence on both positive and negative self-assessments. These findings indicate that both spatial cognitive abilities and spatial self-assessments have a crucial role in mediating the age effect on a measure of environment orientation.

Spatial knowledge acquisition is based on the construction of mental representations – or mental maps (Tolman, 1948) – defined as flexible internal representations of the structure of an environment (Wolbers & Hegarty, 2010). In the spatial cognition domain, it is widely accepted that spatial skills influence the adequacy of mental representations of an environment, which is typically tested in individuals given new environment information to learn (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; see the classification of spatial cognition activities in Montello & Raubal, 2012). Studies on young adults have shown that spatial abilities – in the sense of the capacity to generate, retain and transform abstract visual images (Lohman, 1979) – sustain the goodness of mental representations drawn from new environment learning (e.g. Allen, Kirasic, Dobson, Long, & Beck, 1996; Hegarty et al., 2006; Pazzaglia & Meneghetti, 2012). Spatial self-assessments, recorded by means of questionnaires on sense of direction and/or strategies used to orient oneself, have also been found to be positively related to spatial learning (e.g. Pazzaglia & De Beni, 2006). In a systematic study using the structural equation modeling (SEM) approach, Hegarty et al. (2006) demonstrated that both spatial abilities (measured with objective spatial tasks such as the Embedded Figures Test (EFT, Oltman, Raskin, & Witkin, 1971) and the Mental Rotations Test (MRT, Vandenberg & Kuse, 1978)) and spatial self-assessments of sense of direction (using the Santa Barbara Sense of Direction questionnaire, Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002) predicted the learning of a new environment from real or virtual exploration.

Processing resources such as working memory (WM) have also been shown to have a relevant role in environment learning and processing of spatial information (presented verbally as in Brunyé & Taylor, 2008, or visually – using maps – as in Coluccia, Bosco, & Brandimonte, 2007, or through navigation as in Labate, Pazzaglia, & Hegarty, 2014), either alone or jointly with spatial abilities and spatial self-assessments (e.g. Baldwin & Reagan, 2009; Meneghetti, De Beni, Gyselinck, & Pazzaglia, 2013).

Overall, research in the spatial domain on young adults has advanced our understanding of how spatial abilities, self-assessments and WM influence environment learning, but the combined effects of these variables have not been considered in young or older adults, nor across the adult lifespan. Surprisingly few studies have analyzed spatial resources and competences in relation to environment knowledge in older adults, or across the adult lifespan, despite their crucial influence on individuals' personal autonomy in everyday life.

The literature on aging has examined mental representations drawn from learning new environments using different types of input, testing them by means of different tasks. In general, these studies found older adults less efficient in learning a new environment and more impaired in terms of the properties of the mental representations they formed after receiving different inputs (navigation — Kirasic, 2000; Wilkniss,

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* Corresponding authors at: Department of General Psychology, Via Venezia, 8, 35131 Padova, Italy. Tel.: +39 049 8276622; fax: +39 049 8276600.
E-mail addresses: chiara.meneghetti@unipd.it (C. Meneghetti), erika.borella@unipd.it (E. Borella).

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Jones, Korol, Gold, & Manning, 1997, or maps — e.g. Wilkniss et al., 1997, or descriptions of environments — Meneghetti, Borella, Grasso, & De Beni, 2011). The few studies on the role of spatial skills in older adults' acquisition of new environments indicated that, although spatial abilities decline with aging (Borella, Meneghetti, Ronconi, & De Beni, 2014; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990), they are related to spatial learning. For instance, the performance of young and older adults in spatial tasks like the MRT has been found to be positively related to environment learning from a map (Meneghetti, Fiore, Borella, & De Beni, 2011; Pazzaglia & De Beni, 2006) or through real navigation (Kirasic, 2000). Only the study by Kirasic (2000) systematically examined the relationship between age, spatial abilities (measured with objective spatial tasks) and environment representation (using navigational input), and the latter was operationalized in environment learning (testing the ability to infer spatial information by positioning landmarks on a map, or recognizing a scene, for instance) and way-finding behavior (i.e. finding a landmark in an environment learnt by navigation). Using the SEM approach, Kirasic found that: i) age-related differences in environment learning ability were mediated by the general spatial ability factor, but they also had a direct influence on environment learning; and ii) environment learning was the only direct determinant of way-finding behavior, while age and spatial abilities had only an indirect effect on this ability. These results indicate that the influence of age and spatial abilities on way-finding behavior is mediated by environment learning. This type of result suggests that other variables (such as spatial ability), as well as age (as typically emerges from group comparisons in aging studies, e.g. Wilkniss et al., 1997), intervene in explaining environment learning performance. A limitation of Kirasic's study lies, however, in that an extreme-groups design was used (young vs older adults), and no spatial self-assessments or processing resources (WM) were considered. Although they have been less thoroughly investigated in aging, spatial self-assessments have a role in supporting spatial activities in older adults too, being related to performance in tasks that involve pointing to places after map learning (Pazzaglia & De Beni, 2006), and in spatial tasks (such as EFT and MRT; Borella et al., 2014).

It is clear from the above-mentioned studies that analyses on environment representation have focused on new environment learning. It is recognized that another aspect of spatial cognition concerns people's ability to orient themselves in the environment, to locate their own position ("where you are") in relation to a given reference point (a landmark or cardinal point, for instance; Montello, 2013), when the environment is new (e.g. Ishikawa & Montello, 2006; Lawton & Morrin, 1999) or familiar, as in the case of a map of their home town (Montello, 2010). The ability to orient oneself in one's surroundings is particularly important for older people too (as suggested by Meneghetti, Borella, Fiore, & De Beni, 2013), as they move around the places where they live on a daily basis, they need to retain their orientation skills in order to find and reach destinations, new addresses, and so on. In the present study, we opted to assess environment knowledge in terms of the ability to orient oneself by pointing in cardinal directions of one's own place of residence. Although this is a very quickly-implemented and ecological task, no studies on older adults have examined this ability, while some evidence on young adults encouraged us to adopt this measure because of its relationship with spatial skills. The orientation ability tested using pointing tasks was related to spatial skills recorded with objective tasks like the MRT (Meneghetti, Pazzaglia, & De Beni, 2011) and to spatial self-assessments (Pazzaglia & De Beni, 2006). Hence our interest in examining the relationship between age and environment orientation, and assessing whether intervening variables such as spatial skills and self-assessments, and WM mediate this relationship, as suggested by studies examining new environment learning (Kirasic, 2000).

The main aim of the present study was to use a variety of indicators to analyze the relationship between age, spatial skills (gleaned from objective tasks and spatial self-assessments), WM and environment orientation (as measured by tasks involving pointing in cardinal directions) across the adult lifespan (from 20 to 91 years of age). Objective and self-assessment measures of spatial skills were recorded because of their relevance to environment orientation performance tasks, which has been clearly demonstrated in young adults (Allen et al., 1996; Hegarty et al., 2006), and suggested by some evidence in older adults too (Kirasic, 2000; Meneghetti, Fiore, et al., 2011). Tasks measuring WM were included as well because of its role in complex cognitive spatial skills (e.g. Borella et al., 2014; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). WM also appears to mediate the age-related differences in spatial abilities (Salthouse, Mitchell, Skovronek, & Babcock, 1989).

The SEM approach was used to examine the pattern of the relationships between age, WM, spatial abilities, spatial self-assessments and environment orientation (cardinal points). The SEM is a statistical approach allowing simultaneously testing different relationships between variables – in our case, between age (expressed on a continuum from 20 to 91 years old), WM, objectively ascertained spatial abilities, spatial self-assessments, and environment learning performance – by testing the relationships between variables organized in a certain order and controlling for their interrelation (e.g. Kline, 2005). For the first time, to our knowledge at least, we used SEM to examine the relationship between variables (WM, objective spatial abilities and spatial self-assessments) that are theoretically assumed in the spatial cognition domain to influence environment learning performance (operationalized in our case in terms of pointing in cardinal directions), but whose role has never been tested simultaneously in young and older adults, nor across the adult lifespan.

First we tested the structure of the measures of spatial abilities and spatial self-assessments (single vs separate constructs) to newly ascertain whether these skills represent two separate but related constructs across the adult lifespan (as found by Hegarty et al., 2006, but only in young adults) or whether they are parts of a single general spatial ability factor. Judging from initial evidence of age-related differences in spatial abilities and spatial self-assessments (Borella et al., 2014), we would expect to see the two-factors model extend to a lifespan perspective too. It is worth noting that different self-assessment measures were considered together here for the first time, including sense of direction, pleasure in exploring, spatial anxiety, and pleasure in visiting known places, and it may be that these variables represent not one single factor but several different sub-factors.

Second, different models tested how age, WM, spatial abilities and spatial self-assessments are related to performance in pointing in cardinal directions. Given the well-established relationships between age and WM (e.g. Borella, Ghisletta, & de Ribaupierre, 2011), and between WM and spatial abilities (Miyake et al., 2001), and given some evidence of a relationship between WM and spatial self-assessments (Baldwin & Reagan, 2009), in our Model 1 – based on the SEM approach (see Fig. 2) – we expected age to have a direct link to WM, which in turn may mediate age-related variance in both spatial abilities and spatial self-assessments. Further, given the positive relationships between age and spatial abilities (Borella et al., 2014; Kirasic, 2000), and between age and spatial self-assessments (Borella et al., 2014; Pazzaglia & De Beni, 2006), we explored whether age also influenced these factors directly. Spatial abilities and spatial self-assessments were expected to have a direct influence on environment orientation task performance (as suggested by Hegarty et al. (2006) in young adults, and by Kirasic (2000) in older adults). We therefore explored whether age-related effects on performance in pointing in cardinal directions are mediated by spatial skills (measured objectively and subjectively), which are in turn influenced by age and WM. Since the relationship between age, WM, and pointing in cardinal directions had yet to be examined, we also tested whether pointing performance was influenced directly by age, and also whether WM is related directly to pointing performance (in Models 2 and 3, respectively).

Table 1
Demographic characteristics of participants in the seven age brackets.

	20–29		30–39		40–49		50–59		60–69		70–79		>80		*F* (6, 443)	n_p^2
	N = 42; 48% F		*N* = 92; 49% F		*N* = 78; 55% F		*N* = 66; 47% F		*N* = 37; 51% F		*N* = 64; 44% F		*N* = 71; 53% F			
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*		
Age	23.81	2.84	34.18	3.17	45.19	45.19	53.30	3.30	63.35	2.64	74.25	2.82	84.11	2.75		
Years of schooling	13.05	1.72	11.98	11.98	10.82	3.12	10.29	3.72	10.51	4.74	8.78	4.20	7.75	3.88	14.06*	.16
Vocabulary level	47.24	9.48	49.17	9.42	48.04	9.26	48.58	8.26	52.05	9.55	48.28	9.90	48.11	11.38	1.06	.01

Note. F = females.
* $p < .05$

1. Methods

1.1. Participants

The study involved 450 people from 20 to 91 years of age, divided into seven age brackets (people in their twenties to eighties), with 37 to 92 participants in each age group (see Table 1).

Participants were residents of various cities all over Italy. They were community dwellers and volunteers recruited by word of mouth. A health and demographic questionnaire was used to ensure that participants had no ongoing psychiatric or neurologic diseases (and were not taking any psychoactive drugs), and that they had completed their academic careers according to the normal schedule. None of the participants had reportedly worked in occupations that demand specific training in visuospatial and navigation skills, such as architects, engineers, or drivers, who have a higher spatial profile (Kozhevnikov, Kosslyn, & Shepard, 2005).[1] They were all autonomous and moved around their hometowns on a daily basis.

All participants performed above the cutoff for their age and education in WM tasks (Backward Digit Span and Backward Corsi blocks — see description below and Italian norms (De Beni, Borella, Carretti, Marigo, & Nava, 2008)). Older adults (aged 60 years or more) all had a good cognitive functioning, achieving a score of at least 27 in the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). All participants had normal or corrected-to-normal vision.

The numbers of males and females did not differ significantly across the age groups. All participants had completed their compulsory education in Italy (attending school for at least 8 years) and all except the oldest of them had attended secondary or high schools. The participants' vocabulary scores (Wechsler, 1981) did not differ across the decades considered (for the sample's demographic details, see Table 1).

2. Materials

2.1. Spatial tasks

Shortened versions (s) of tried and tested tasks (see the battery standardized by De Beni et al., 2014) were used, which preserved a good internal reliability, comparable with that of the original versions (see Table 2; see also Borella et al., 2014).

The short Embedded Figure Test (sEFT, adapted from Oltman et al., 1971) involves identifying simple shapes (shown separately) embedded in a more complex overall figure (10 items).

The short Mental Rotations Test (sMRT, adapted from Vandenberg & Kuse, 1978) involves finding two objects (3D figures) out of four that match the target figure but in a rotated position (10 items).

The short Object Perspective Taking task (sOPT, adapted from Kozhevnikov & Hegarty, 2001) contains a set of objects and a circle for providing the answer. Participants are asked to imagine being at one object, facing another, and pointing to a third; they use the circle to answer by drawing an arrow out from the center towards the edge of the circle (6 items).

2.2. Spatial self-assessment measures

The Sense of Direction and Spatial Representation Scale (SDSR; Pazzaglia & De Beni, 2006; De Beni et al., 2014) measures general sense of direction. The SDSR is composed of 11 items (e.g. "I think I am a person with a good sense of direction"). The judgment is expressed using a Likert scale from 1 (not at all) to 5 (very much).

The Spatial Anxiety Scale (SAS; adapted from Lawton, 1994; De Beni et al., 2014) measures the degree of anxiety experienced in environmental situations. The SAS comprises 8 items identifying environmental situations (e.g. "Going to an appointment in an unfamiliar part of the city") expressing the degree of anxiety they arouse from 1 (not at all) to 6 (very much).

The Attitudes towards Orientation Tasks (AtOT; De Beni et al., 2014) scale measures the degree of pleasure in exploring new and well-known places. It consists of 10 items expressing pleasure in exploring (e.g. "I like to find new roads to reach familiar places", 5 items) or in visiting known places (e.g. "When I'm traveling or visiting a new city I like somebody to guide me", 5 items).

2.3. Working memory tasks

The Backward Corsi task (Corsi, 1972) and the Backward Digit Span test (see De Beni et al., 2008) were used. The former involves tapping the same series of randomly-distributed blocks on a board as the examiner, but in reverse order, while in the latter participants repeat sequences of digits, again reversing their order of presentation. Participants are asked to reproduce increasingly long sequences (2–7 blocks, or 2–8 digits), with two trials for each sequence length. After two consecutive recall errors, the task is discontinued.

2.4. Cardinal direction pointing task

This task involves pointing in the four cardinal directions. The question asked is, "From where we are, which way is north/south/east/west?" (the four points are presented in a balanced order). Participants use their arm to point in the chosen direction and the experimenter records their answer by drawing a line out from the center of a circle towards the perimeter.

2.5. Procedure

Participants were tested in quiet rooms at community centers during two individual sessions lasting about 50 min each. In session 1, they completed a health and demographic questionnaire, and a vocabulary test, and then they performed the cardinal direction pointing task and the WM tasks in a balanced order. To familiarize them with the pointing task, participants were asked to identify a place outside their

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[1] Participants were employed in the following occupations: 16 students, 178 manual workers (e.g. farmers, mechanics, bricklayers, painters, artisans), 208 intellectual workers (e.g. secretaries, technical advisers, tradespeople, teachers, nurses, self-employed lawyers, business consultants), and 48 were unemployed (or did occasional jobs).

Table 2
Descriptive statistics and internal consistency of all measures administered to participants.

	Cronbach's alpha[a]	20–29		30–39		40–49		50–59		60–69		70–79		>80		*F* (6, 443)	n_p^2
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*		
Backward Digit Span test	.88	4.88	1.09	5.08	1.24	4.85	1.21	4.30	1.04	3.86	0.95	3.88	0.93	3.66	0.77	19.89*	.21
Backward Corsi test	.90	5.38	1.06	5.07	1.07	4.40	1.12	4.18	1.18	3.95	1.03	3.81	0.85	3.52	0.75	26.84*	.27
Pointing in cardinal directions (north)		25.31	26.04	32.85	32.76	28.77	32.93	41.56	59.34	48.59	56.76	36.92	48.28	35.79	41.30	1.56	.02
Pointing in cardinal directions (south)		26.21	26.96	33.43	32.89	29.33	33.08	42.33	59.76	46.14	58.04	32.95	37.63	35.44	39.31	1.39	.02
sEFT[b]	.90	8.71	2.06	8.45	2.01	6.90	2.80	6.80	2.94	6.73	3.26	5.06	3.06	2.89	2.39	39.10*	.35
sMRT[b]	.81	5.64	2.78	4.67	2.94	3.23	2.50	3.67	2.59	2.92	2.28	1.53	1.50	1.30	1.03	27.54*	.27
sOPT[c]	.80	239.02	217.00	214.41	179.77	248.05	141.52	300.83	185.62	329.73	218.10	427.55	220.09	544.89	230.72	26.02*	.26
Sense of direction	.80	42.07	9.58	41.32	10.03	39.74	8.12	41.33	9.26	39.95	7.13	44.27	8.20	42.59	7.82	1.99	.03
Spatial anxiety	.87	18.98	5.29	20.48	7.59	21.79	7.57	20.76	8.10	23.73	7.57	22.20	7.54	25.13	6.31	4.71*	.06
Pleasure of exploration	.78	18.52	5.66	19.34	5.26	18.35	4.55	18.83	4.31	17.84	4.02	18.08	4.51	17.11	3.90	1.77	.02
Pleasure in visiting known places	.83	16.45	4.90	15.85	5.84	18.28	5.43	16.52	5.83	17.70	5.30	18.56	5.21	20.15	4.11	5.77*	.07

Note. sEFT: short version of the Embedded Figures Test; sMRT: short version of the Mental Rotations Test; sOPT: short version of the Object Perspective Taking task.

* $p < .05$.

[a] Cronbach's alpha for the long versions was .80 for sEFT, and .90 for sMRT and sOPT (De Beni et al., 2014).

[b] The descriptive statistics of the sEFT and sMRT referred to the accuracy for the ten items (higher values corresponding to greater accuracy).

[c] The descriptive statistics of the sOPT referred to the degrees of error in the six items (higher values corresponding to higher degrees of error, i.e. worse accuracy).

home (a supermarket, church etc.) and use their arm to point in the direction of its location. Then the experimenter asked them to point north, south, east and west. Participants used their arm to point in each direction and the experimenter recorded their answer using a circle (printed on a sheet of paper). In session 2, three spatial tasks and self-assessment questionnaires were presented in a balanced order (i.e. alternating between objective tasks and questionnaires, and creating twenty possible task–questionnaire combinations). For each spatial task, participants first read the instructions and practiced with some examples. Time limits of 5 min were imposed for the spatial tasks.

3. Results

3.1. Scoring

For the sEFT and sMRT, one point was awarded for each correct answer (two correct options for the sMRT and one correct option for the sEFT). For the sOPT we calculated the absolute degrees of error between the answers given and the right answer.

For the spatial self-assessment measures we calculated the sum of the Likert values for all items (for the SDSR and SAS) and for the two sub-aspects (for the AtOT).

For the WM tasks the final score corresponded to the length of the longest correctly-repeated sequence.

For the cardinal direction pointing task, having used a compass to correctly establish the cardinal points in relation to the participant and the position of the place where they were being tested, we calculated the absolute degrees of error between the participants' answers and the right answer (i.e. the actual direction of the cardinal points).

The final scores for the sEFT, sMRT and WM tasks were a measure of accuracy (high scores corresponding to a better performance). The final scores for the sOPT and cardinal direction pointing task expressed the degrees of error (higher scores corresponding to a worse performance), as is usually the case (e.g. McNamara, 2012). As for the spatial self-assessment measures, higher final scores coincided with a stronger sense of direction or greater spatial anxiety, pleasure in exploring, or pleasure in visiting known places and, vice versa, and lower scores corresponded to weaker or lesser degrees of these constructs.

3.2. Descriptive statistics

Reliability (Cronbach's alpha) and descriptive statistics are given in Table 2. Correlations between visuospatial measures, working memory and age are shown in Table 3.

3.3. Confirmatory factor analyses

Preliminary confirmatory factor analyses were completed first to assess the measurement qualities of each construct and of the general alternative models, and then to test the relationships between the factors. The R program (R Development Core Team, 2011) was used with the "lavaan" package (Rossel, 2012). Since the variables observed were not exactly normally distributed, a maximum likelihood estimation was used, obtaining robust standard errors and a Satorra–Bentler scaled test statistic (Satorra & Bentler, 1988). The fit indices used are presented in Table 4. Each latent variable hypothesized was marked by at least two indicators.

3.4. Factor compositions

We examined whether spatial abilities and self-assessments are parts of a single general factor or two separate, but related, constructs. The single-factor solution yielded an unacceptable fit, $\chi^2 = 310.07$, $df = 14$, $p < .001$, $CFI = 0.71$, $TLI = 0.57$, $SRMR = 0.11$, $RMSEA = 0.22$, $BIC = 21{,}764.36$, so we tested whether spatial abilities and spatial self-assessments represent two different constructs (as in Hegarty et al.,

Table 3
Correlation matrix for the measures of interest and age.

	1	2	3	4	5	6	7	8	9	10	11
1. Age	–										
2. Backward Digit Span test	$-.44^{***}$	–									
3. Backward Corsi test	$-.50^{***}$	$.43^{***}$	–								
4. Pointing in cardinal directions (north)	.08	$-.12^{*}$	$-.17^{***}$	–							
5. Pointing in cardinal directions (south)	.05	$-.10^{*}$	$-.15^{**}$	$.92^{***}$	–						
6. sEFT	$-.57^{***}$	$.38^{***}$	$.45^{***}$	$-.17^{***}$	$-.15^{**}$	–					
7. sMRT	$-.50^{***}$	$.30^{***}$	$.47^{***}$	$-.15^{**}$	$-.13^{**}$	$.51^{***}$	–				
8. sOPT	$.48^{***}$	$-.37^{***}$	$-.39^{***}$	$.14^{**}$	$.11^{*}$	$-.56^{***}$	$-.48^{***}$	–			
9. Sense of direction	.07	.01	$.15^{**}$	$-.12^{**}$	$-.15^{**}$	$.17^{***}$	$.21^{***}$	$-.14^{**}$	–		
10. Spatial anxiety	$.21^{***}$	$-.14^{**}$	$-.22^{***}$	.08	$.11^{*}$	$-.23^{***}$	$-.32^{***}$	$-.13^{**}$	$-.35^{***}$	–	
11. Pleasure in exploring	$-.12^{**}$	$.11^{*}$	$.24^{***}$	−.09	$-.13^{**}$	$.24^{***}$	$.28^{***}$	$-.17^{***}$	$.61^{***}$	$-.46^{***}$	–
12. Pleasure in visiting known places	$-.22^{***}$	$-.13^{**}$	$-.25^{***}$	.08	$.10^{*}$	$-.33^{***}$	$-.43^{***}$	$.27^{***}$	$-.43^{***}$	$.61^{***}$	$-.56^{***}$

Note. For abbreviations see Table 2; $N = 450$.
The negative value of the correlations between pointing in cardinal directions north and south and the sOPT, with the spatial measures (objective and subjective) and WM tasks had a positive meaning, i.e. smaller degrees of error in the sOPT and pointing in cardinal direction tasks were associated with a higher accuracy in objective measures or higher scores in subjective measures.
*** $p < .001$.
** $p < .01$.
* $p < .05$.

Table 4
Fit statistics for different confirmatory factor analyses based on all participants. In boldface is the best model (Model 1b).

	df	$SB\chi^2$	*p*	*CFI*	*TLI*	*SRMR*	*RMSEA*	*BIC*
Reference				Bentler (1990)	Tucker and Lewis (1973)	Jöreskog and Sörbom (1981)	Steiger and Lind (1980)	Schwarz (1978)
Direction				Large is good	Large is good	Small is good	Small is good	Small is good
Range				[0, 1]	Can fall outside [0, 1]	≥0	≥0	
Model 1 (9b)	45	173.33	<.001	0.94	0.92	0.06	0.08	36,299.99
Model 1b (15b)	**47**	**177.27**	**<.001**	**0.94**	**0.92**	**0.05**	**0.08**	**36,296.81**
Model 2 (15c)	46	175.33	<.001	0.94	0.92	0.05	0.08	36,297.31
Model 3 (15d)	46	175.40	<.001	0.94	0.92	0.05	0.08	36,297.31

Note. $SB\chi^2$: Satorra–Bentler scaled chi-square; CFI: comparative fit index; TLI: Tucker–Lewis index; SRMR: standardized root mean square residual; RMSEA: root mean square error of approximation; BIC: Bayesian Information Criterion.

2006). Confirmatory factor analyses showed a good fit for the three spatial tasks, indicating that the spatial latent variable adequately describes the data, $\chi^2 = 1.88$, $df = 2$, $p = 0.39$, $CFI = 1.00$, $TLI = 1.00$, $SRMR = 0.01$, $RMSEA = 0.001$, $BIC = 12{,}315.24$. Given the unacceptable fit of the single-factor solution for the self-assessments, $\chi^2 = 49.25$, $df = 2$, $p < .001$, $CFI = .91$, $TLI = .73$, $SRMR = 0.26$, $RMSEA = 0.05$, $BIC = 11{,}268.24$, we tested a two-factor solution, distinguishing between positive and negative self-assessments. This latter solution fitted with the data, $\chi^2 = 0.02$, $df = 1$, $p = 0.88$, $CFI = 1.00$, $TLI = 1.01$, $SRMR = 0.001$, $RMSEA = 0.001$, $BIC = 11{,}208.39$, and this distinction was maintained in the subsequent analyses. We thus distinguished between three different latent variables: spatial abilities, and positive and negative spatial self-assessments (see Fig. 1).

For the cardinal direction pointing task[2] the factor including all four cardinal points was tested and revealed an inadequate fit, $\chi^2 = 229.65$, $df = 2$, $p < .001$, $CFI = .64$, $TLI = -0.08$, $SRMR = 0.21$, $RMSEA = 0.99$, $BIC = 17{,}832.36$, so only pointing north and south was included in the pointing in cardinal directions latent variable (i.e. this latent variable comprised pointing both north and south, given their high correlation [$r = .92$, $p < .001$]) (see Fig. 1).

The WM tasks were represented by two measures, and they formed the WM latent variable given their fairly good correlation ($r = .43$, $p < .001$), consistently with the literature (Borella et al., 2011) (see Fig. 1).

The measurement model based on the constructs of interest was acceptable, $\chi^2 = 89.80$, $df = 44$, $p < .001$, $CFI = 0.98$, $TLI = 0.97$, $SRMR = 0.04$, $RMSEA = 0.05$, $BIC = 34{,}514.77$ (see Fig. 1).

The latent variables were defined as explained above and only the relationships between the latent variables were modified in the models presented below.

3.4.1. Models 1 and 1b: structure and results

In Model 1 we assumed that age-related differences in pointing in cardinal directions are mediated by spatial abilities and positive and negative self-assessment factors. At the same time, WM was expected to mediate age-related differences in spatial abilities, and positive and negative spatial self-assessments, while it was expected to contribute only indirectly to the pointing in cardinal directions. We also tested the direct path between age, spatial abilities and positive and negative self-assessments (see Fig. 2, Model 1 — panel on the left). The results showed that Model 1 had an acceptable fit (see Table 4) and that the paths from age to the spatial abilities latent variable, and from the negative self-assessments latent variable to the pointing in cardinal directions latent variable were not significant (as shown with dotted lines in Fig. 2).

In a subsequent model (Model 1b), we therefore deleted the above-mentioned non-significant paths and we maintained the other path relations proved to be significant in the Model 1 (as shown in Fig. 2, Model 1b — panel on the right). In particular, the goodness of Model 1b was confirmed by the smaller Bayesian Information Criterion (BIC; Schwarz, 1978) for Model 1b than for Model 1, and the calculation of the approximate Bayes factor (Raftery, 1995) – $\exp[(\mathrm{BIC}_{\text{model }1} - \mathrm{BIC}_{\text{model }1\text{b}}) = 4.90]$ – showed that Model 1b was nearly five times better than Model 1.

3.4.2. Model 2: structure and results

Model 2 tested whether there was a direct effect of age on pointing in cardinal directions (as suggested by studies showing age-related differences in spatial performance, e.g. Wilkniss et al., 1997). Model 2 was similar to Model 1b, but with the addition of a direct path from age to pointing in cardinal directions in order to test whether or not all the

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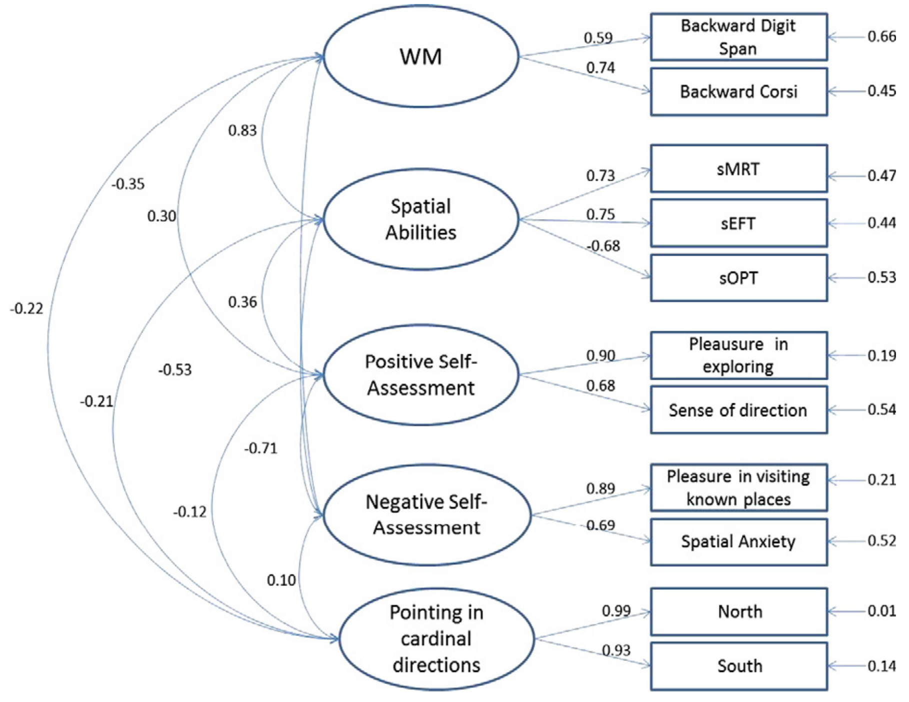
[2] We ascertained that pointing in cardinal directions did not vary as a function of the geographical area. The results of a comparison of the pointing performance between groups of participants in different Italian regions, distinguishing between northern (i.e. Veneto, Trentino–Alto Adige and Lombardia), central (Marche, Toscana, and Abruzzo) and southern regions (Puglia, Calabria, Basilicata), revealed no significant differences in pointing performance ($F < 1$). Performance in pointing in cardinal directions also correlated with pointing to places identified by participants in the familiarization phase of the task ($r = .46$, $p < .01$).



Note: For abbreviations see Table 2.

Fig. 1. Measurement model including working memory, spatial abilities, positive and negative self-assessments, and pointing in cardinal directions. *Note*: For abbreviations see Table 2.

age-related variance is mediated by spatial abilities and spatial self-assessments. The results showed that the path between age and the pointing in cardinal directions latent variable was not significant. Although the fit was acceptable for Model 2 (as shown in Table 4), the approximate Bayes factor of 1.2 indicated that Model 1b was slightly better than Model 2.

3.4.3. Model 3: structure and results

Model 3 tested whether there was a direct effect of WM on pointing in cardinal directions (as suggested by studies showing the effect of WM on spatial performance, e.g. Borella et al., 2014). Model 3 was similar to Model 1b, but with the addition of a direct path from WM to pointing in cardinal directions. The results showed no significant path between WM and the pointing in cardinal directions latent variable. Here again, although Model 3 showed an acceptable fit (see Table 4), the approximate Bayes factor of 1.2 indicated that Model 1b was slightly better than Model 3.

Model 1b was thus judged to best represent the data.[3]

4. Discussion

The aim of the present study was to investigate the relationship between environment orientation – assessed in terms of a person's ability to point in cardinal directions from their position in their own home town (because this represents a modality to test environment knowledge; Montello & Raubal, 2012), age, objectively and subjectively-measured spatial skills, and WM throughout the adult lifespan. Although it has been demonstrated that aging coincides with a decline both in environment learning skills (e.g. Wilkniss et al., 1997), and in cognitive abilities such as WM (e.g. Borella et al., 2011) and spatial abilities (e.g. Borella et al., 2014), no research has been conducted to examine the concomitant role of spatial abilities, spatial self-assessments and WM in explaining age-related effects on environment orientation, taking a whole adult lifespan perspective. Using an SEM approach, we thus tested: (i) how the measures administered constituted different factors representing spatial skills (and whether these latent variables were distinguishable between objective and subjective measures), WM and accuracy in pointing in cardinal directions; and (ii) the relationship between age, WM, spatial skills (objectively and subjectively measures) and environment orientation.

Concerning the factor composition, we found that spatial abilities and spatial self-assessments should be considered not as a single general factor, but as two separate factors. This not only is consistent with work done by Hegarty et al. (2006), but also newly extends this finding to age-related effects over the adult lifespan. Spatial self-assessments should also be further separated into two latent variables (not seen as a single variable), one positive and represented by sense of direction (as considered in Hegarty et al., 2006) and pleasure in exploring new environments, the other negative and represented by spatial anxiety and pleasure in visiting known places. In our subsequently developed models, we therefore considered spatial abilities, and positive and negative spatial self-assessments separately.

Concerning the relationship between the variables of interest, our SEM results showed that spatial abilities and positive self-assessments predicted participants' efficiency in orienting themselves based on

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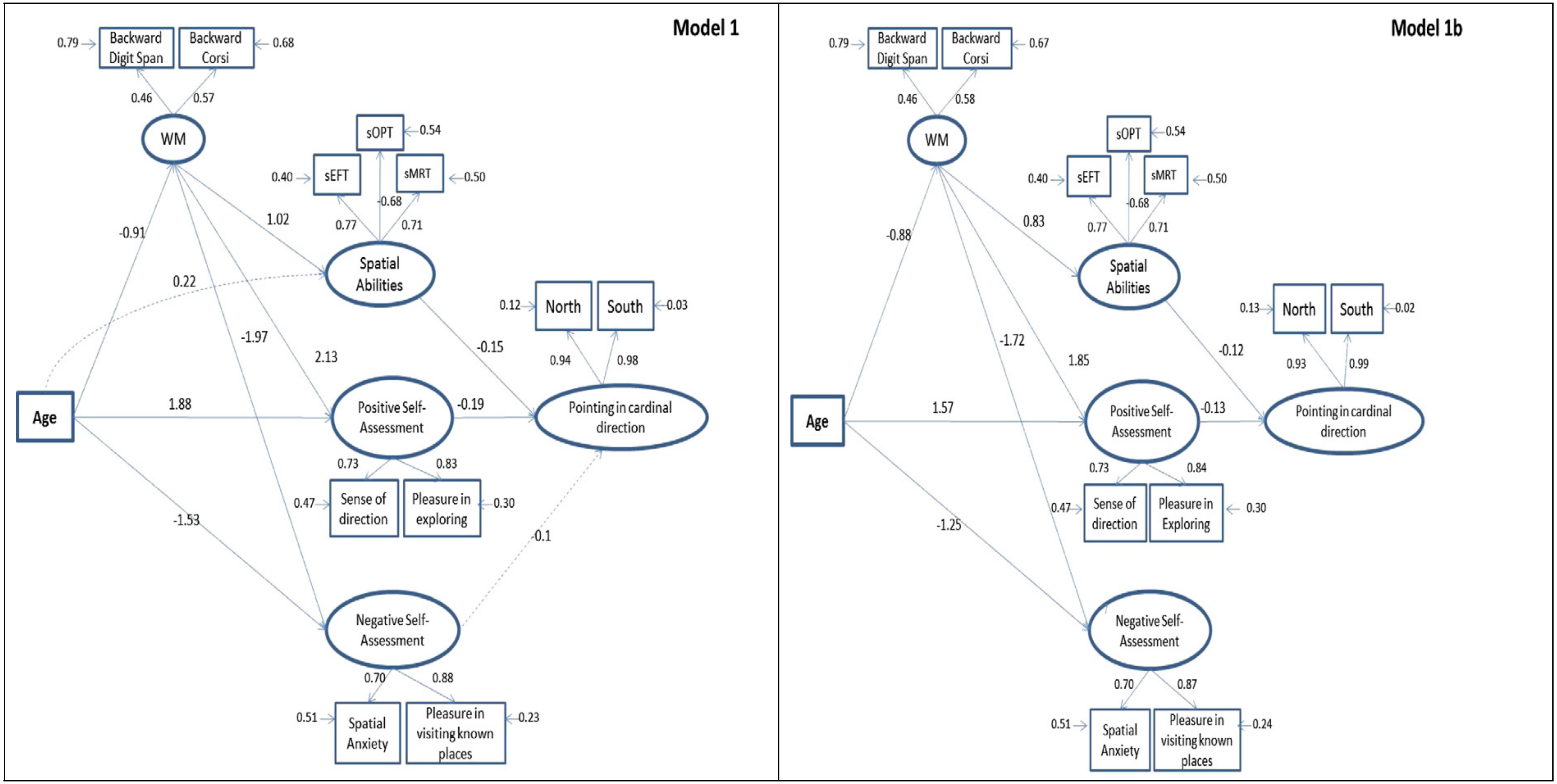
[3] To make sure that Model 1b was really the best and its goodness did not change under the influence of other variables, we also checked for the role of education (as the sample differed in level of formal education, though all participants had at least 8 years of schooling). The new model in which education was added as an initial predictor at the same level as age did not differ from Model 1b (scaled Chi square difference test; Satorra & Bentler, 1988 – χ^2 diff $_{(\text{df diff} = 8)} = 11.4$, $p = .18$). This result led us to conclude that education did not contribute significantly in Model 1b. We also checked the role of gender because this is a relevant factor in spatial measures (Linn & Petersen, 1985), and gender-related differences were found in three measures included in the models (sMRT, $d = 0.80$; Pleasure in exploring and Sense of direction, $d = 0.50$; the d values indicate the Cohen's (1988) effect sizes derived from the comparison between males and females: these are large for the sMRT and Pleasure in exploring and medium for the Sense of direction - males performing better than females). So two models were run separately for males and females, testing the same relations as in Model 1b. Good fit indices emerged for both genders: female model, $\chi^2 = 96.47$, $df = 47$, $p < .001$, $CFI = 0.95$, $TLI = 0.93$, $SRMR = 0.04$, $RMSEA = 0.067$, $BIC = 18{,}142.83$; male model $\chi^2 = 117.11$, $df = 47$, $p < .001$, $CFI = 0.95$, $TLI = 0.93$, $SRMR = 0.04$, $RMSEA = 0.08$, $BIC = 17{,}818.13$; and this result confirmed that the pattern of the relations in Model 1b was acceptable for both males and females.



Note: For abbreviations see Table 2.

Fig. 2. Structural models 1 (panel on left) and 1b (panel on right): the standardized solutions are presented for each path in each model. The model with the best fit is Model 1b. *Note*: For abbreviations see Table 2.

cardinal points. Good objectively-measured spatial skills and positive self-assessments therefore both contributed to a better spatial performance when tested using cardinal directions to orient oneself in space. These results show that: (i) spatial abilities are related to environment orientation abilities (as in Hegarty et al. (2006) as concerns young adults, and in Kirasic (2000) for young and older adults tested on their new environment learning skills); (ii) spatial self-assessments are related to environment orientation abilities (as in Hegarty et al. (2006) for young adults, and in Pazzaglia and De Beni (2006) for older adults administered new environment learning tasks), but we have newly introduced the distinction between positive and negative self-assessments; in fact, (iii), positive self-assessments (concerning sense of direction and pleasure in exploring new environments) explained pointing accuracy, whereas negative self-assessments (spatial anxiety and a negative attitude to exploring the environment) had no influence on pointing accuracy.

Taking the role of WM into account, our results showed that WM only influences accuracy in pointing in cardinal directions indirectly, mediated by spatial abilities and positive self-assessments. Consistent with previous studies on young adults, these results indicate that WM underpins the processing of spatial stimuli and relates to spatial abilities (Miyake et al., 2001; Salthouse et al., 1989) and positive self-assessments (see Baldwin & Reagan, 2009), rather than to the ability to point in cardinal directions per se. This pattern of findings also suggests that a more efficient WM enables a more flexible allocation of resources to sustain cognitive functioning (i.e. spatial abilities) and positive subjective attitudes towards environment knowledge and orientation, which in turn enable people to orient themselves in space. This latter result means that having greater resources in basic cognitive mechanisms (such as WM) facilitates a positive self-assessment (as shown by Baldwin & Reagan, 2009; Meneghetti, Pazzaglia, & De Beni, 2011). WM was also negatively associated with a likelihood of dysfunctional spatial attitudes (i.e. spatial anxiety and taking pleasure in visiting known places) and, although this result needs to be explored more thoroughly, it generally supports the relationship between WM and dysfunctional emotional conditions (e.g. for a review Whitmer & Gotlib, 2013).

As for the role of age, it revealed a direct influence on spatial self-assessments, indicating that people's opinions of their own attitudes to environment learning and orientation skills (be they positive or negative) became stronger with age, as found sometimes in previous studies (Pazzaglia & De Beni, 2006), but not always (e.g. Meneghetti, Fiore, et al., 2011). In addition, our findings show that, although negative self-assessments did not directly influence pointing accuracy, they were related to WM and age factors, suggesting that they have a relevant role across the life span.

The relationship found between age and WM confirmed previous reports (e.g. Borella et al., 2011), while the relationship between age and spatial abilities was only indirect, mediated by WM. This would mean that WM has a core role in spatial abilities, confirming that it is a variable capable of mediating the relationship between age and complex cognitive activity (Salthouse & Ferrer-Caja, 2003) behind age per se.

The results of the present study thus indicate that age-related differences in individuals' ability to orient themselves using cardinal points is mediated by their functional spatial skills (operationalized here in terms of spatial abilities and a positive spatial attitude) and it is not explained directly by age. Our finding that age influences spatial performance indirectly through the intervention of other variables (spatial abilities and positive spatial self-assessments in our case) is consistent with the previous report from Kirasic (2000). Nevertheless, it is to note that Kirasic did not consider processing resources (such as WM, considered here) or subjective measures (as considered by Hegarty et al. (2006) in young adults), and only young vs older adults were compared in his study. Our results suggest that the relationship between age and environment knowledge – be it a matter of learning a new environment (as in Hegarty et al., 2006; Kirasic, 2000), being able to orient oneself in the environment (as in our study) – is mediated by other variables, such as the spatial skills and WM tested in our sample.

Although it is intriguing, the use of environment orientation ability as a dependent measure is an intrinsic limitation of our study because, having tested environment orientation, we cannot guarantee that the relationship between age, WM and spatial skills works to a similar extent when it comes to learning a new environment (as in previous studies, Hegarty et al. (2006), Kirasic (2000)). Further studies consequently need to ascertain whether this pattern of relationships is confirmed when a new environment is learnt (using different inputs too, such as navigation and/or map learning). Other variables may also intervene in modulating the relations between age, spatial skills and environment learning performance. Indeed, since cognitive task performance in aging can be influenced by education level (e.g. Verhaeghen, 2003), and spatial experience (e.g. Salthouse et al., 1990), it will be important in further models to ascertain their role in the pattern of relations found between age and environment learning performance.

Overall, our results make an important contribution to our theoretical knowledge of how age, WM and spatial abilities work together in explaining environment orientation efficiency (as measured by pointing in cardinal directions), and age-related effects from an adult lifespan perspective. Using SEM and taking a whole lifespan perspective, we showed for the first time that: i) objective and subjective measures of spatial skills are distinct factors; ii) self-assessments of spatial abilities can be separated into positive and negative judgments of spatial competences; iii) spatial abilities and positive self-assessments contribute directly to environment orientation efficiency using cardinal points; and iv) WM mediates age-related differences in objectively and subjectively measured spatial abilities (although age also has a direct influence on these skills). This study is relevant because it represents a new research approach that conjugates individual differences in spatial abilities with age in environment orientation efficiency. The findings are of interest for their potential implications in clinical interventions and training programs, even for older adults: action to sustain their WM performance, spatial abilities and positive self-assessments may help them to preserve their environment orientation skills (using cardinal directions, at least), with a potentially positive fallout on their well-being in their surroundings.

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