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Research Article

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Search Strategies Used by Older Adults in a Virtual Reality Place Learning Task

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Purpose of the study: Older adults often have problems finding their way in novel environments such as senior living residences and hospitals. The purpose of this study was to examine the types of self-reported search strategies and cues that older adults use to find their way in a virtual maze.
Design and Methods: Healthy, independently living older adults (n = 129) aged 55–96 were tested in a virtual maze task over a period of 3 days in which they had to repeatedly find their way to a specified goal. They were interviewed about their strategies on days 1 and 3. Content analysis was used to identify the strategies and cues described by the participants in order to find their way. Strategies and cues used were compared among groups.
Results: The participants reported the use of multiple spatial and non-spatial strategies, and some of the strategies differed among age groups and over time. The oldest age group was less likely to use strategies such as triangulation and distance strategies. All participants used visual landmarks to find their way, but the use of geometric cues (corners) was used less by the older participants.
Implications: These findings add to the theoretical understanding of how older adults find their way in complex environments. The understanding of how wayfinding changes with age is essential in order to design more supportive environments.

Key words: Wayfinding, Hippocampus, Strategies, Cues, Environment, Aging

The ability to find one's way in the environment, known as wayfinding (Passini, Pigot, Rainville, & Tetreault, 2000), is essential for maintaining independence in the world. However, it can be a significant problem for many older adults. Older adults have been shown to have more difficulty finding their way in novel or changed environments; they are slower to learn environments, less efficient, and make more errors in directional heading compared with younger people (Moffat, 2009). The consequences of wayfinding failures can be severe. Problems with wayfinding are shown to impact independence with a decrease in driving and interaction within neighborhoods, and a fear of getting lost (Davis, Therrien, & West, 2008; Kirasic, 2000; Moffat & Resnick, 2002). Getting lost, a consequence of poor wayfinding ability, can cause distress, fear (Chiu et al., 2004; Tu & Pai, 2006) and less interaction within the world.

Even though it is well documented that people have a decline in wayfinding ability with aging, built environments that older adults encounter are often unsupportive of wayfinding. For example, senior residential apartments and assisted living residences are often designed with long, double barrel corridors; equally spaced non-salient doors; and a general lack of any perceptual cues. Although there is research support for some wayfinding enhancements, such as signage (Vilar, Rebelo, & Noriega, 2012) there are few studies that have given evidence for ways to enhance environments for older adults based on how older adults perceive environments and learn best. This is partially due to the fact that there is limited understanding about how aging affects ones' environmental learning strategies (Moffat, 2009). A better understanding of wayfinding abilities and ways to support wayfinding is needed in order to maximize independence and well-being in aging.

Wayfinding is a complex phenomenon, dependent upon sensory and cognitive abilities. When individuals are unfamiliar with an environment, they may use a specific visual landmark such as a tower in order to find their way. Becoming more familiar, they may begin to use landmarks in a more sophisticated way to make navigation decisions, such as using consecutive landmarks to determine when to turn on a route (Foo, Warren, Duchon, & Tarr, 2005). The most adaptable way to find one's way is to use a cognitive map (Tolman, 1948), which is an internal representation or memory of an environment based on the relationships among the environmental information, such as landmarks and other geographical features (Bures, Fenton, Kaminsky, & Zinyuk, 1997; O'Keefe, 1991; O'Keefe & Nadel, 1978). Upon re-exposure to the learned environment, people retrieve the learned cognitive map and have a sense of knowing where they are so they can navigate where they desire to go. For example, most people can recall a cognitive map of their neighborhood—they can find their way from most any starting point and they are not reliant on any one landmark to know where they are. Cognitive maps are adaptable because individuals take shortcuts or alternative routes when necessary, and function optimally without getting lost. This process of environmental knowing is frequently referred to as allocentric in nature.

Age Related Changes in Place Learning

Evidence suggests that the hippocampal formation (HPC) and related structures in the medial temporal lobe of the brain are necessary for encoding cognitive maps (Parslow et al., 2004)—a process termed *place learning* (Allen, 1999; Jacobs, Thomas, Laurance, & Nadel, 1998). The HPC is one of the earliest structures to show atrophic changes with aging (Raz, Rodrigue, Head, Kennedy, & Acker, 2004). In addition, a decline in sensory abilities is common in aging, changing how information from the environment is perceived. Thus, place learning may be impaired when there are HPC and sensory changes due to aging or disease.

A consequence of age-related differences in place learning is that older adults, compared to younger adults, may compensate for lost abilities by using different search strategies while they are learning new environments (Moffat, 2009). Wayfinding strategies have been described in many different ways, but are frequently described as either egocentric or allocentric (Antonova et al., 2009; Rodgers, Sindone III, & Moffat, 2012). Using an egocentric strategy (often called route or landmark strategies), an individual may remember a route or directions using the self as a reference point. For example, a person may remember a sequence of landmarks at which to turn right or left in order to reach a destination. If the expected landmarks are not present, the individual is lost because successful navigation relies on the wayfarer's relationship to the specific landmarks. In contrast, for allocentric strategies (i.e., cognitive maps such as in knowing one's neighborhood), individuals use a frame of reference outside of themselves to learn a location (Rodgers et al., 2012). It has been shown in several studies that older adults are less likely to use allocentric strategies, perhaps due to HPC changes, than younger people and are more likely to use egocentric strategies (Rodgers et al., 2012).

Another way to classify wayfinding strategies is using a framework of decision making. For example, Garling (1999) defines strategy as "a sequence of mental operations that bring the decision maker from the initial state of indecisiveness concerning possible actions to a final state of decisiveness, in which one course of action is chosen" (p. 83). Using this framework, the decision about which way to go or how to explore an environment involves the ability of the person to deliberate on the best possible choice and finalize a decision about how to proceed in the wayfinding task. Garling hypothesizes that for any wayfinding task in large scale space, individuals develop an action plan, formulate a travel plan, and execute it. They receive information about the properties of the environment through research (media) and exposure which give feedback for the development and execution of the plan.

The use of virtual water maze tasks, assumed to be the gold standard task to test place learning in humans, has provided new methods to measure spatial strategies. These virtual reality (VR) simulations are frequently based on the Morris Water Maze (MWM) task, in which rodents must find their way in a pool of water to a submerged platform, using only external maze cues to learn their location (Morris, 1983). Animals tested in the MWM have been shown to have place learning deficits with age (Bizon et al., 2009), female gender (Veng, Granholm, & Rose, 2003), and with hippocampal damage (Pearce, Roberts, & Good, 1998).

In human studies, VR environments that replicate the MWM task have shown similar findings to those in animals; mainly that place learning is impaired in older adults (Moffat & Resnick, 2002), more often in females (Mueller, Jackson, & Skelton, 2008), and in those with hippocampal damage as indicated by functional magnetic resonance imaging (Livingstone & Skelton, 2007). In addition, learning in virtual mazes has been shown to transfer into real world situations (Foreman, Wilson, Duffy, & Parnell, 2005), further supporting the validity of this type of testing.

VR maze tasks can give important information about wayfinding strategies. For example, some researchers have examined strategies based on swim or walking paths in VR MWM tasks. Schoenfeld, Moenich, Mueller, Lehmann, and Leplow (2010) used a computer program to analyze the swim paths of adults in a virtual MWM. They identified three different types of search strategies, including (a) place strategies (allocentric), in which participants headed directly towards the platform; (b) landmark strategies (egocentric), in which participants went towards a salient landmark; and (c) indirect strategies, in which participants searched near a deleted landmark in a probe trial. Similarly, Rodgers and colleagues (2012) conducted a two-pronged study in which younger and older adults were given an option of using an egocentric or allocentric strategy to solve a maze problem. First, participants were determined to use either allocentric or egocentric strategies based on their performance in a virtual Y maze task. Then participants were tested in a virtual MWM task and performance on the virtual MWM was correlated with the strategy preferred in the Y maze task. Results showed that the older adults overwhelmingly preferred an egocentric strategy in the Y maze task, whereas younger adults preferred an allocentric strategy over 50% of the time. For younger adults, using an allocentric strategy in the Y maze was positively correlated with performance in the virtual MWM, but not for the older adults, possibly because so few older adults chose an allocentric strategy; or possibly because older adults may not use allocentric strategies as effectively as younger adults.

In addition to these studies, several researchers have asked participants about the strategies they use while being tested in a wayfinding task. For example, Driscoll, Hamilton, Yeo, Brooks, and Sutherland (2005) questioned older adults about the types of strategies they used in a virtual MWM task and coded the responses as either place strategies or random strategies. Place strategies were defined as any in which the subject identified the use of a distal cue, and random strategies were defined as all other strategies. They found that younger individuals employed the use of place strategies more than older adults.

The reviewed research provides a beginning supposition that older adults use allocentric strategies less frequently than younger adults, which may be related to a decline in place learning performance. A deficit in the literature is that the definitions of allocentric and egocentric strategies are not standardized and vary substantially between studies. Confining the definition of strategies people use to only egocentric and allocentric strategies may be limiting. In addition, determining strategies by looking at walking or swim paths requires a decision by actually looking only at the outcome of the strategy. By only looking at the outcome and then deducing the strategy, it is possible that alternative explanations (i.e., ineffective application of a strategy due to motor or sensory deficits) are not examined. In addition, most studies identified only one strategy classification per subject, when it is probable that persons use multiple strategies or combinations of strategies when learning new environments.

Study Purpose

Thus, the purpose of this study was to (a) identify the self-reported strategies used by older adults who are asked to find their way in a virtual maze; (b) to determine if there are differences in strategy use with respect to age and gender; and (c) to determine if there are differences in strategies used over time (3 days of exposure). For this study, the term strategy was defined as the self-identified process or plan with the intention of solving a spatial navigation task. The results of this study can be used to understand the wide variability in performance across age and gender, and provide guidance for interventions to improve wayfinding performance in older adults.

Design and Method

Participants

This study was part of a larger study by Davis and Therrien (2012) in which place learning was examined across three age groups of adults, including group 1 aged 55–64; group 2 aged 65–74; and group 3 aged 75 and older so that we would have a large enough sample to determine changes in wayfinding ability and strategy use across ages. Briefly, the convenience sample was recruited from the senior centers, independent living facilities, places of worship, and the community via flyers, verbal presentations, and word of mouth. To be in the study, individuals must have met the following inclusion criteria: (a) living independently; (b) aged 55 or older; (c) vision 20/40 with correction if needed; (d) no self-reported cognitive, psychological, or neurological illnesses or problems; (e) mini-mental status scores 24 or higher, indicating a low probability of dementia; (f) not taking medications that could impair cognitive functioning; and (g) physically able to use a computer joystick; and (h) no history of vertigo.

A total of 187 individuals contacted the researchers via phone with an interest in being in the study. Of those, 45 were not enrolled due to exclusion criteria (i.e., history of neurologic disease, severe eye disease, other; *n* = 16), the timing of the study (*n* = 13), acute health issues (*n* = 2) and other various reasons. A total of 142 subjects were initially enrolled in the study. Of this group, 10 were found to not meet the inclusion/exclusion criteria upon assessment. An additional three subjects were not included in the study; one withdrew from the study because of simulation sickness (vertigo/dizziness, a common consequence of VR studies), one withdrew because of not enjoying the study, and one was not included because the day 1 data were not recorded due to interview error. This left the total sample size for the study at 129 subjects.

Procedures

In the parent study, individuals who agreed to participate after having the study explained by the researcher, signed an informed consent document and were given a battery of tests. These included a demographic survey, several cognitive measures, and measures of mobility and social network size. Then, after training to proficiency on the use of a computer joystick, they were tested in a virtual MWM program called the computer-generated arena (University of Arizona, n.d.), in which they were asked to find their way to a hidden platform on a computer screen by moving throughout the virtual space using a joystick. The only cues to the location of the platform were pictures on the wall. Participants were tested in four different cue conditions, which varied with respect to the types of cues present. Each of the four cue conditions had eight pictures on the wall (Figure 1) which were the only extra-maze cues present; and there were no intra-maze cues. Participants were given six trials in each of the four cue conditions for each of three consecutive days. A detailed description of the method is reported elsewhere (Davis & Therrien, 2012).

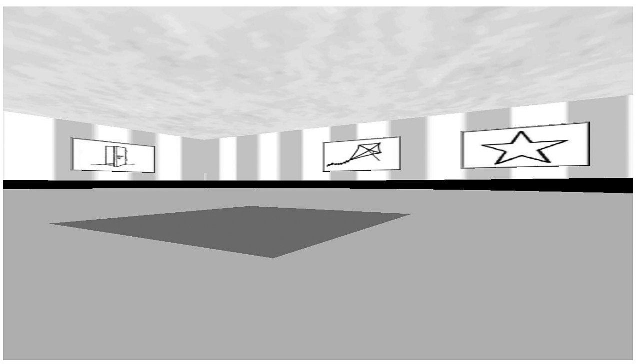

Figure 1. Computer-generated arena. This is a screen shot of one of the cue conditions in the computer-generated arena. Participants had to find the hidden platform (made visible here) repeatedly for six trials. There were eight pictures on the wall. There were a total of four cue conditions (different pictures) in which participants had to find the hidden platform for a total of six trials in each cue condition for 3 days in a row.

The current study is reporting the results of interviews, which were conducted at the end of testing on day 1 and again on day 3. The interviews took place in the location of the data collection, which was in the participants' own residences or in a private room in the place of recruitment (i.e., senior center) or the University. For the interviews, the participants were seated in a comfortable chair after completing the VR wayfinding task. Trained data collectors used an interview guide (Table 1) and recorded the interviews. Minor prompts, such as "Tell me more about that" were included as needed in the interviews.

Tapes from interviews on day 1 and day 3 were transcribed verbatim into a word processing program, removing names and any identifying information. This study reports the data from the interviews in terms of themes of wayfinding strategies and cues.

Measures

Demographic variables, including age and gender, were collected using a survey developed by the researchers. Cognitive measures included the mini-mental status examination (MMSE), the Digit Span tests, the Money Roadmap test of Direction Sense, and the Trail Making test. The MMSE (Folstein, Folstein, & McHugh, 1975) is an 11-item screening tool that assesses orientation, attention, immediate and short-term recall, language, and spatial ability. The MMSE is sensitive in detecting cognitive decline and in identifying those at high risk for dementia, with a score of less than 24 being considered at risk for dementia (Crum, Anothony, Bassett, & Flostein, 1993). The Digit Span tests (Weschler, 1987) were used to assess working memory and attention. Subjects are asked to repeat an increasingly larger series of numbers in the Digit Span Forwards test (DSF); in the Digit Span Backwards test (DSB), subjects repeat the numbers in reverse order. Normal scores for the DSF test are ≥5, and ≥4 for DSB. Test-retest reliability of the Digit Span tests range from 0.66–0.89 (Lezak, 1995). The Money Roadmap test of Direction Sense was used to determine right-left direction sense from an egocentric spatial perspective. In this test, participants are shown a line drawing of a route which

Table 1. Interview Questions

1.	Can you tell me how you found the hidden platform?
2.	If you had to tell others how to find the hidden platform, what would you tell them?
3.	What made finding the platform easier?
4.	What made finding the platform challenging?
5.	Is there anything else you'd like to tell us?

is placed on a table. The examiner traces the route, and participants indicate if they are turning right or left. Subjects receive a score of up to 32 points based on the number of correctly identified turns (Money, Alexander, & Walker, 1965). Finally, the Trail Making test (Lezak, 1995) is a two-part test of attention, working memory, and visual tracking. In Trail A, participants are asked to connect a series of numbers in order, which are circled and displayed randomly on an 8×10 sheet of paper. Trail B requires participants to alternately connect a series of numbers and letters in order. The test is scored based on the time it takes for the participants to complete the task.

For the qualitative data collection, an interview guide was established by the researchers after conducting several studies on wayfinding using the same VR program, and by reviewing the gaps in the literature. The questions were designed to allow for exploration of self-identified strategies and cues used. Most studies categorize participants into using either allocentric or egocentric strategies based solely on performance; or by use of a questionnaire that presupposes that only these two types of strategies exist. Our prior work has demonstrated a great deal of variability in place learning performance (Davis & Therrien, 2012; Davis, Therrien, & West, 2008), which may be due to differences in the strategies used (Moffat, 2009). We desired to uncover the strategies and cues used as perceived by the participants to develop a better understanding of their experiences.

Data Analysis

For this study, both qualitative and quantitative methods were used. First, content analysis was used to analyze the transcribed interview data. In content analysis, qualitative data in written or verbal form is broken down into units and coded with attention to themes or clusters that may emerge (Polit & Beck, 2008). The researchers used categorical distinctions that identified units based on commonalities. Inductive coding was used, meaning that the researchers did not develop codes prior to analyzing the data, but rather let the codes emerge from the data which were then grouped into themes based on commonalities. For example, subjects mentioned swirling, vacuuming, using a grid, etc. while trying to find their way; eventually these codes were grouped under the theme of psychomotor strategies.

Two content-expert researchers coded the data independently by hand using the first five interviews. Consensus on the codes was achieved after discussion, and an initial template was made of the codes identified and agreed upon. Ten more interviews were then coded by both researchers using the template. The researchers then met, compared coding schemes, and revised the template. Inter-rater reliability was established by comparing coding between the two reviewers on five interviews until reliability was established with >90% agreement. Then, all interviews (including the first 15) were coded using the revised template. As new codes were uncovered, the interviews were reread and recoded to include the new codes. When the coding was completed, the codes were grouped under like categories, which were collapsed into themes. A total of 288 codes related to place learning strategies yielded eight strategy themes; for the cues, a total of 217 codes yielded six cue themes. The themes produced the strategies and cues discussed in this article.

The quantitative analysis was performed using SPSS Version 17.1 (SPSS, Chicago, IL). Chi-square tests were used to determine differences in strategies and cues reported among age and gender groups, with a significance level set at $p \leq .001$ to account for the number of statistical tests on the sample. To determine differences between the three age groups with respect to number of strategies, analysis of variance was used with a Scheffe post hoc criterion for significance. The McNemar test was used to determine differences in the distribution of responses regarding the use of specific strategies from day 1 to day 3.

Results

Sample

On day 1, 129 participants completed the interview, and 121 participants completed the interview on day 3. There were no statistical differences among age groups with respect to years of education, gender, ethnicity, or cognitive status. However, as expected, the older participants were more likely to be single. The age groups were not different with respect to the MMSE, Money Roadmap test, or Digit Span tests. However, there were significant differences among groups with respect to the Trails A and B tests, with the oldest age group showing more significant impairment (higher scores) than the other age groups (Table 2).

Self-Reported Strategies for Place Learning

From the initial codes, eight separate strategy themes were identified, including: (a) lining up with cues/pictures/corners; (b) psychomotor strategies; (c) random movement; (d) distance strategies; (e) using memory; (f) lining up with one specific cue; (g) searching a specific quadrant; and (h) triangulating among three or more environmental features/cues (Table 3). Most individuals reported using more than one strategy, ranging from 0–5 strategies, with no difference in the number of strategies used for the group as a whole between day 1 and day 3 (mean 2.08 strategies on

Table 2. Comparison of Participants' Characteristics by Age Group

Demographic variables	Group 1, 55–64 years, $n = 43$	Group 2, 65–74 years, $n = 45$	Group 3, ≥75 years, $n = 41$	(*df*) *F*	Chi square (*df*)	*p* value
Age (*M*, *SD*)	59.2 (2.89)	69.1 (2.83)	82.00 (5.8)	(2, 126) 339.92		.0001
Years education (*M*, *SD*)	14.97 (3.41)	14.01 (2.95)	13.70 (3.3)	(2, 125) 1.621		.202
Female (*n*, %)	27 (63%)	29 (69%)	26 (61%)		0.65 (2)	.721
Married (*n*, %)	26 (61%)	23 (51%)	14 (34%)		5.96 (2)	.051
Has financial needs (*n*, %)	13 (30%)	6 (13%)	5 (19%)		5.78 (2)	.056
Non-White (*n*, %)	11 (26%)	5 (11%)	4 (9%)		5.03 (2)	.081
MMSE (*M*, *SD*)	29.19 (1.15)	29.04 (1.09)	28.73 (1.32)	(2, 126) 1.596		.207
DSF (*M*, *SD*)	6.39 (1.21)	6.59 (1.24)	6.64 (1.29)	(2, 128) 0.229		.796
DSB (*M*, *SD*)	4.91 (1.32)	4.52 (1.24)	4.52 (1.25)	(2, 128) 1.255		.289
Roadmap test (*M*, *SD*)	27.84 (4.92)	26.43 (5.63)	26.07 (4.88)	(2, 128) 1.397		.251
Trails A (*M*, *SD*)	36.09 (18.52)	39.91 (11.53)	51.95 (15.30)	(2, 127) 12.38		<.0001
Trails B (*M*, *SD*)	79.02 (42.27)	91.98 (32.44)	131.30 (54.32)	(2, 127) 16.50		<.0001

Notes: Subject characteristics were compared among the groups. The total *n* in this table is for participants who completed at least one interview. DSB = Digit Span Backwards; DSF = Digit Span Forwards; MMSE = mini-mental status examination; Roadmap test = Money Roadmap test of Direction Sense; Trails A and B values are reported in seconds.

Table 3. Place Learning Strategy Themes Identified in the Analysis

Strategy	Description of the strategy
Lining up with cues/pictures/corners	Finding a location between a picture and the corner of the room and searching in that area repeatedly.
Psychomotor	Using the joystick to move strategically across the arena floor in a pattern.
Random movement	Moving the joystick randomly until the platform is found.
Distance	Determining how far away from the arena wall the platform is located and searching that area.
Memory	Remembering where the platform was from a prior trial and going to that same location again.
Lining up with one cue	Finding one specific cue, like a picture, and going directly towards it repeatedly.
Searching a specific quadrant	Determining the spatial area where the platform is located and searching the general area.
Triangulation	Imagining the location of the platform between three or more environmental features, such as in the middle among three pictures.

day 1, and 2.03 strategies used on day 3). However, a few subjects could not clearly identify any strategies used on day 1 ($n = 7$, 5.3%) and on day 3 ($n = 7$, 5.8%). These subjects did not identify a strategy but mentioned cues. For example, one subject who did not specify any particular strategy said, "Watch the pictures because they are very important"—even with prompting, the participant was unable to say how the pictures were used.

Lining Up With Cues/Pictures/Corners

The most common strategy used on day 1 was lining up with more than one picture, or other geometric features (corners, wallpaper, parts of pictures). For example, one subject recommended that one should "pick an object and its relationship with another object.... I basically focus on an object and what's next to it to find the hidden platform." This strategy was reported more frequently on day 1 ($n = 66$, 51%) than on day 3 ($n = 45$, 37%; $p < .0001$; McNemar test).

Psychomotor Strategies

The next most frequently identified strategies were those that were psychomotor. Psychomotor strategies were described as moving the joystick in a pattern, or covering the virtual territory in a structured way. For example, one subject described the strategy in this way: "I started kind of angling, picking out one of the [pictures] on the wall and angling in a straight line and then going to another and then angling from one across the room from one point to another point based on the symbols on the wall to not be repeating my circumference." Participants named this strategy with many terms, including "surfing," "mowing," "plowing," "swirling," "circling," and "vacuuming." Use of this strategy did not significantly differ across days (day 1: $n = 50$, 39%; day 3: $n = 42$, 35%; $p = .644$; McNemar test).

Random Movement

Many of the participants reported not using a strategy, especially at first, and finding the platform randomly. One subject described this as, "Well, first I felt like it was pretty random, but then I started to…line it up with things on the wall." Some people described finding the hidden platform as "pure luck," "by accident," or that they found the target by wandering. For example, one subject advised, "I just wandered around and went every other way. Just go on around and look around. As fast as you can." Random strategies were identified similarly across days (day 1: $n = 35$, 27%; day 3: $n = 22$, 18%; $p < .150$; McNemar test).

Distance Strategies

Many participants described the importance of using depth and distance in knowing where the platform was located. To do this, they often used the walls or arena in order to determine how deep in the room they were located. Others used the middle of the room as a reference point to determine their distance. For example, one subject described, "I used the distance from the wall, using the black line [the arena wall]…" Distance strategies were identified similarly on day 1 ($n = 30$, 23%) and day 3 ($n = 27$, 22%; $p = .50$; McNemar test).

Memory

Some participants were unable to describe how they knew where the platform was, except they remembered its location from prior trials or days. One subject described this strategy as "I kind of remembered approximately where they were from the other days and tried going around them." Notably, significantly more participants used a memory strategy on day 3 ($n = 53$, 44%) than day 1 ($n = 30$, 23%; $p < .0001$; McNemar test).

Lining Up With One Specific Cue/Feature

Other participants reported they lined themselves up with one specific cue or geometric feature. One subject advised that one should "Pick out your target picture and know that that the…platform is kind of in front of it." Another stated the way to find the platform was to "line them up with…generally one picture that looked right when it was up close…line it up with that each time." There was no difference in the reported use of this strategy between day 1 ($n = 66$, 51%) and day 3 ($n = 45$, 37%; $p = .50$; McNemar test).

Searching a Specific Quadrant

Some participants described searching, recalling, or locating a specific area and returning to that area to find the target. One subject stated, "I tried to see where it (the platform) was, and try to move to that area." Others described this type of searching as going to the "general vicinity" or the "general territory" where they thought the platform was located. There was no difference in the use of this strategy between days ($n = 10$, 15% on day 1; $n = 26$, 22% on day 3; $p = .311$; McNemar test).

Triangulation

Triangulation was used by certain participants in order to find the hidden target. To triangulate, participants stated that they imagined the location of the target in relation to three or more environmental features. For example, one subject stated, "Within each of the [cue conditions], I picked up three [pictures], I guess the word is 'triangulate.' So the triangulation strategy worked for the subsequent [trials]." Others were unable to identify the term triangulation, but described using at least three environmental features in order to recall the platform's location. For example, one subject stated, "I think I would tell them to pick…reference points on the figures, and on two of them, coordinate that with a corner…I was using the spread between the butterfly wings and the tip of the umbrella for my reference points." Words such as "angling," "square," "triangle," and "rectangle" were used to describe this strategy. Often, participants used a combination of pictures or portions of pictures and corners of the room to triangulate. There was a trend for triangulation to be identified more often on day 3 ($n = 16$, 13%) than on day 1 ($n = 9$, 7%; $p = .021$; McNemar test).

Differences in Strategy Use by Age Group

The mean number of strategies reportedly used among the three age groups was significantly different on day 1, $F(2, 126) = 4.632$, $p = .011$. Post hoc analysis using the Scheffé post hoc criterion for significance indicated that the youngest age group used significantly more strategies ($M = 2.37$, $SD = 1.02$) than the oldest age group ($M = 1.66$, $SD = 1.04$; $p = .009$) but not the middle age group ($M = 2.07$, $SD = 1.16$). There were no significant differences among the groups regarding the number of strategies used on day 3.

A chi-square analysis was used to determine the differences in reported strategy use by age group. On day 1, the analysis was significant for distance strategies, $\chi^2(2, n = 129) = 17.147$, $p \leq .0001$, with the younger age group more likely to report using this strategy ($n = 19$, 44%) than the other age groups (65–74 age group), $n = 8$, 18%; ≥75 age group, $n = 3$, 7%). On day 3, the groups were significantly different with respect to triangulation, $\chi^2(2, n = 121) = 14.292$, $p = .001$, with the oldest age group less likely to report using triangulation ($n = 3$, 7.5%) when compared to the youngest age group ($n = 12$, 29%). There were no other significant differences in strategy use by age group.

Differences in Strategy Use by Gender

Results indicated that on day 1 there was a trend for males to use more strategies ($M = 2.28$, $SD = 1.28$) than females ($M = 1.90$, $SD = 0.98296$), $t(127) = 1.881$, $p = .062$, but not on day 3. Chi-square analysis was used to determine if there was a difference in the types of strategies identified by the males versus females, with no significant differences found.

Cue Use

Participants reported using a variety of environmental features as landmarks in completing the place learning task. These included: pictures, corners, wallpaper stripes, the floor, and the arena wall. By far the most common environmental features used for place learning were reported to be the pictures on the wall, on both day 1 (n = 122, 95%) and day 3 (n = 113, 93%). The least mentioned environmental feature deemed helpful in place learning was the floor on both day 1 (n = 3, 1%) and day 3 (n = 5, 4%).

To determine if the types of environmental features used differed among age groups, a chi-square analysis was performed with the groups and the types of cues as variables. The analysis showed a trend among the groups in the identification of corners as cues ($\chi^2 = 10.208(2)$, $p = .006$), with the youngest age group reporting more use of corners (n = 20, 49%) than the 65–74 age group (n = 10, 25%) and the ≥75 age group (n = 7, 18%). There were no other significant differences among the groups.

Discussion

This study described the types of strategies and cues that people 55 years and older reported using when place learning in a virtual environment. The main finding from this study was the identification of multiple spatial and psychomotor strategies and cues that people described to help them find their way. In addition, we found that two strategies—triangulation and a distance strategy—were used less often by the oldest age group when compared to the other age groups. Finally, our data suggest that people use multiple strategies for wayfinding, in contrast to most studies which only identify one type of strategy.

Several studies have examined the strategies people use for wayfinding. In many studies, it is assumed that people can only use allocentric strategies in virtual mazes like the one used in this study. However, our study indicates that people are able to use some nonspatial strategies, such as searching in a grid, going in circles, etc., and egocentric strategies (i.e., moving towards one specific cue) in these environments. Older adults, who may be limited in their use of allocentric abilities, are adaptable in that they use multiple types of strategies in order to find their way.

It has been shown in multiple studies that place learning performance is impaired with aging (Moffat, 2009), and that males are superior at place learning tasks when compared to females (Mueller, Jackson, & Skelton, 2008). Our study results showed that the oldest participants and those who were female (across ages) reported the use of significantly fewer strategies on day 1 than the younger participants and the male participants. This may be due to a decline in the ability to switch between strategies and maintain flexibility when one strategy does not work. When challenged by a complicated new environment, individuals may try out fewer strategies or get “stuck” using an inefficient strategy. Our results support those of Harris and Wolbers (2014) who found that older adults were less likely than younger adults to switch back and forth from allocentric to egocentric strategies in a VR wayfinding task. They concluded that older adults have a “general strategy switching deficit” (p. 1100). Thus, environmental conditions that are likely to require strategy switching (i.e., blocked or changed routes, complex environments, novel environments) may be especially challenging for older adults.

Another reason that older adults have fewer strategies identified on initial learning (day 1) may be related to a decline in allocentric abilities as a result of age-related hippocampal changes (Rodgers et al., 2012). The current study included participants whose age ranged from 55 to 96 years of age. Thus, it would be expected to see differences in the types of strategies used, with the older adults less likely to employ allocentric strategies than the younger group. We found that the oldest age group was less likely to use a distance strategy on day 1 (meaning they tried to find the middle of the arena and move strategically closer or further away from the wall), and less likely to use triangulation on day 3 than the younger groups. In fact, no participants in the oldest age group used triangulation on day 1, and only three participants used it on day 3. Of all of the strategies people identified, triangulation is the most allocentric, as it involves understanding the location of the platform based on the relationship among three or more cues in the environment. The distance strategy seems decidedly egocentric, as individuals using this strategy attempt to determine how far they are from the edge of the arena. Thus, the study results are suggestive of the proposition that in aging, hippocampal based allocentric strategies may decline as well as other types of strategies.

The three age groups were similar in the types of environmental features they reported as helpful in place learning task, with the extramaze wall pictures reportedly used by almost all subjects. There was a trend for the oldest subjects to report less use of corners when compared to the younger subjects. This supports the results of our previous studies, which have shown that as individuals age, they have an increased reliance on salient environmental cues (Davis & Therrien, 2012; Davis, Therrien, & West, 2009). Many senior residential environments have long double-barrel corridors with little environmental information—these environments may be especially hard for older adults to learn and remember.

The strengths of this study were that the design allowed us to learn new information about the types of strategies people identify in spatial navigation tasks, and that we examined learning over time by interviewing participants during initial and longer term learning. However, there are limitations; mainly that some participants were unable to identify their own strategies. In addition, although we compared self-identified strategy use between days 1 and 3, it is possible that strategy use changes even more frequently (i.e., trial to trial or even second to second). Our sample was also somewhat limited in terms of diversity of ethnicity and socioeconomic status. Finally, we had smaller numbers of subjects using some of the themes which limited our analysis.

In conclusion, this study illuminates the complexity of place learning in a virtual MWM task. Older persons use multiple strategies to find their way, some of which change over time and with age. Older age is associated with the use of fewer strategies on initial learning. Future studies need to examine the relationships among the types of strategies used, the features of the environment, and the performance outcomes (successful wayfinding) of the place learning task. Further studies using real world environments, and including individual factors such as mobility (i.e., wheelchair, walking) and cognition need to be done to determine how these factors affect wayfinding strategies and performance. In addition, it would be beneficial to examine the effect of purposefully enhancing environments to support the use of the strategies most likely used by older adults. For example, our finding that participants reported high reliance on cue-based strategies supports the need for salient cues to be present in key decision areas in the built environments that seniors inhabit. These interventions would be instrumental in the development of supportive, enriching environments for older adults that will assist them in maintaining their independence.

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