Article

Environment and Behavior
2017, Vol. 49(9) 1038–1065

DOI: 10.1177/0013916516677341
journals.sagepub.com/home/eab
SAGE

Salient Cues and Wayfinding in Alzheimer's Disease Within a Virtual Senior Residence

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Abstract

Wayfinding is a problem for persons with Alzheimer's disease (AD), especially in complex environments such as senior residential communities. In this study, persons with AD or mild cognitive impairment (MCI) and a control group of older adults were asked to navigate a virtual reality simulation of a senior residential community. Subjects had to find their way repeatedly over multiple trials for two consecutive days in standard (no extra cues) and salient (colorful, memorable cues placed at key decision points) cue conditions. The results showed that all subjects found their way faster and more effectively in the salient cue condition than in the standard cue condition. Those in the AD/MCI group were significantly more impaired in wayfinding ability compared with those in the control group. Persons with impaired wayfinding ability due to AD and MCI can find their way more effectively in virtual environments enhanced with salient environmental cues.

Keywords

cognition, elderly/gerontology, legibility, perception, physical activity (walking, cycling, exercise), spatial behavior, wayfinding, simulation, research methods, housing/residential (single-family, multifamily), research setting/place type

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Alzheimer's disease (AD) is the most common cause of dementia, affecting more than 5 million persons in the United States. The symptoms of AD range from mild memory impairment in the early stages to severe loss of cognitive and functional abilities in the end stages of the disease (Alzheimer's Association, n.d.). Getting lost is one of the most troublesome symptoms experienced by persons with AD. In fact, wayfinding, defined as the ability to find one's way from one location to another (Golledge, 1999), is problematic for more than half of persons with AD (Chiu et al., 2004). Wayfinding problems begin in the early stages of AD (Chiu et al., 2004; deIpolyi, Rankin, Mucke, Miller, & Gorno-Tempini, 2007), with up to 42% of these individuals reporting getting lost outside of their homes (Ballard, Mohan, Bannister, Handy, & Patel, 1991). As the disease progresses, wayfinding problems affect the majority of persons with the disease (Passini, Rainville, Marchand, & Joanette, 1995).

The ability to find one's way in the world is essential for independent functioning and social interaction, and the loss of this ability can have serious consequences. Persons with dementia who get lost can experience anxiety (Chiu et al., 2004; Kirasic, 2000; Tu & Pai, 2006). They also have an increased risk of severe injury or death (Rowe, 2003), institutionalization, and becoming a burden on caregivers (McShane et al., 1998).

Older adults with physical and/or cognitive problems, such as early stage AD, often are forced to relocate from a familiar home to a long-term care community (Castle, 2001; Choi, 1996). More than 70% assisted living facility residents have cognitive impairment (Zimmerman, Sloane, & Reed, 2014). While such persons may find learning their way around their new environment challenging, doing so will allow them to engage in social activities, interact with their neighbors, and use facility services. Unfortunately, reduced wayfinding ability combined with the fear of getting lost may lead to decreased exploration and social engagement in these individuals at a time when these elements are essential to their quality of life.

Environmental Supports for Wayfinding

Due to the cognitive and perceptual changes experienced by those with AD, it is important to consider ways to provide environmental support for them during wayfinding. The environmental press model depicts the interrelatedness between the environment and an individual's level of functioning (Lawton & Nahemow, 1973). In this theoretical model, a person's functional ability or *competence* interacts with the demands or *press* of the environment. Environmental press includes any features of the physical or social environment that an individual perceives as challenging. A certain degree of environmental press is stimulating and therefore beneficial. However, sub-optimal function can occur when there is a mismatch between the environmental press and the person's competence (Lawton, 1977, 1990; Lawton & Nahemow, 1973). To avoid this mismatch and help maximize wayfinding in people with AD, environments should be made supportive by addressing the unique cognitive abilities and functional needs of these individuals.

Even though wayfinding problems are common in persons with dementia, very few researchers have examined how to provide more supportive environments for these individuals. In a review of the literature addressing the effect of architectural design on wayfinding in persons with dementia, Marquardt (2011) identified two environmental interventions that may help improve wayfinding in senior communities: floor plan design and environmental cues. Results from studies on floor plan design indicated that long hallways, circulation systems with multiple direction changes, and repetitive elements (such as a hallway lined with identical bedroom doors) act as barriers to wayfinding (Netten, 1989; Passini, Pigot, Rainville, & Tetreault, 2000; Passini, Rainville, Marchand, & Joanette, 1998). In her study of 104 residents of long-term care communities, Netten (1989) also found several elements related to wayfinding problems, including long hallways leading to dining areas, multiple exit points along a route, and monotonous elements such as identical bedroom doors. Other researchers noted that complex environments, such as those requiring residents to take an elevator to another floor to access activities, are especially difficult for individuals with dementia (Passini et al., 2000).

Achieving salience in built environments is a difficult task. Many long-term care communities have floor plan designs that are challenging for wayfinding, and difficult and costly to change. Conversely, adding environmental cues—pieces of sensory information within the environment (Caduff & Timpf, 2008)—to existing facilities is a strategy that is easier to implement and less expensive than major construction projects. It is important to consider environmental cues' effect on wayfinding as they can be used to help differentiate areas and provide information about one's location (Marquardt, 2011). To use cues effectively, space planners and administrators must consider research results that indicate which properties make cues helpful for wayfinding in particular contexts with specific users.

Salient Cues

In their proposed theory of landmark salience for human navigation, Caduff and Timpf (2008) stated that navigation cues must be *salient* features that attract the wayfarer's attention because they are "distinct, prominent, or obvious . . . compared with other features" (p. 250). Put simply, for cues to be effective for wayfinding, individuals must be able to select them from among other sensory information present in the environment. Caduff and Timpf described three components of salience: perceptual, cognitive, and contextual. Perceptual salience describes the properties that make cues stand out from the surroundings such as color, form, size, and location. Cognitive salience describes the wayfarer's ability to allocate mental processes to the cue. Recognizable and relevant cues are more likely to be chosen as wayfinding landmarks because they have meaning to the wayfarer. Finally, contextual salience refers to the type of task and the mode of navigation that influence the resources needed for wayfinding. Accordingly, Caduff and Timpf suggested that the properties of the cue, the cognitive resources of the individual, and the complexity of the wayfinding task are important considerations for achieving landmark salience for human navigation.

There is evidence that persons with AD have difficulty attending to and remembering landmarks during wayfinding. As noted by Caduff and Timpf (2008), before individuals can attend to a cue, they must first select it from the environmental surround and then process the information from the cue into a memory that can be used for wayfinding. Persons with AD often have visual attention deficits (Rizzo, Anderson, Dawson, Myers, & Ball, 2000) that affect their ability to attend to wayfinding cues, especially if the cues are not sufficiently distinct from other environmental information (Foster, Behrmann, & Stuss, 1999). For example, several studies have asked persons with and without AD to recall landmarks after being escorted through a novel route. When compared with the control group (those without AD), persons with AD were significantly impaired in recognizing landmarks (Monacelli, Cushman, Kavcic, & Duffy, 2003) and remembering the order of landmarks on a route (deIpolyi et al., 2007). The results of these studies indicate that persons with AD may have visual deficits that hamper their ability to attend to and process the environmental information needed for wayfinding. For this reason, the salient properties or perceptual salience (Caduff & Timpf, 2008) of navigational cues are critical.

Color

Color is a cue property that may be especially beneficial for wayfinding in persons with AD as it can make a cue stand out from the surround, promoting its perceptual salience. In addition, color can make a cue more identifiable, thus decreasing the information-processing resources needed to remember it. Color perception has been shown to be relatively stable throughout old age in individuals with and without dementia (Wijk et al., 2002). Color can enhance recognition, selection, and memory of environmental cues in older adults

(Wijk et al., 2002; Wijk, Sivik, Steen, & Berg, 2001) as well as those in the early stages of dementia (Cernin, Keller, & Stoner, 2003). Objects with realistic color, meaning that the objects include the colors that people expect to see (e.g., leaves are green and skies are blue), have been shown to be easier for persons with dementia to identify than those with non-realistic colors (Wood, Mortel, Hiscock, Breitmeyer, & Caroselli, 1997).

Despite the evidence that color may be important for object recognition in persons with dementia, few studies have systematically examined the effect of color on wayfinding for this population. In their review of the literature about the use of color in designing spaces for persons with dementia, Tofle, Schwarz, Yoon, and Max-Royale (2004) stated, "The evidence-based knowledge, however, for making informed decisions regarding color application has been fragmented, sporadic, conflicting, anecdotal, and loosely tested" (p. 4). In one small non-randomized study, people with dementia found hospital rooms enhanced with bright color (either red or green) more effectively than non-enhanced rooms; however, the effect was short-lived (Motzek, Bueter, & Marquardt, 2016). Another study found that color was identified by persons with dementia as being important for learning how to find their rooms in a newly redesigned dementia unit (Gibson, MacLean, Borrie, & Geiger, 2004). Therefore, while the use of color has some theoretical support, its usefulness in wayfinding has been understudied.

Familiarity

Another quality that may increase a cue's salience for wayfinding is its familiarity or recognizability to the wayfarer, a trait that Caduff and Timpf (2008) related to cognitive salience. Familiar objects are those that are personally known or meaningful to the wayfarer. For example, a self-portrait or a national flag likely will be more familiar to a person than an abstract painting. The results of two small observational studies showed that placing personal objects in memory boxes outside the rooms of persons with later-stage dementia could help them identify their rooms (Nolan, Mathews, & Harrison, 2001; Nolan, Mathews, Truesdell-Todd, & VanDorp, 2002). The findings of another study showed that using pictures of easily identifiable objects, such as cars and flowers, as cues in a virtual reality (VR) maze helped older subjects without dementia learn the goal location faster and more frequently than did abstract paintings (Davis & Therrien, 2012). Currently, most real-world studies have looked at familiar cues only for identification of one location (i.e., residents' rooms) versus general wayfinding within a large-scale environment, and the VR studies of familiar cues have not included subjects with AD.

Location

Cue location may be important for wayfinding. Location can refer to the placement of a cue (floor, rail, upper wall, or ceiling) or the physical location within a community. Picture cues tend to be placed on the upper part of hallway walls to be aesthetically pleasing. However, there is some evidence that persons with dementia tend to look at the ground and may miss cues that are placed too high (Adachi, 1997; Passini et al., 2000). One study of eye-tracking in persons with early stage dementia found that during wayfinding, those who walked looked more at the ground while those in wheelchairs tended to look just above the handrails (Schuchard, Connell, & Griffiths, 2006). Thus, evidence about ideal wall placement of cues for persons with dementia is inconclusive.

In addition to height, location can refer to where cues are located within a building such as in hallways, at intersections, and outside destinations such as dining rooms and patient rooms. Most wayfinding studies have tested the efficacy of cues placed outside destinations, such as residents' rooms, a practice that improved room recognition even for individuals with late stage dementia (Gibson et al., 2004; Nolan et al., 2001; Nolan et al., 2002). In addition, there is some evidence that persons with AD can recall cues placed at key wayfinding decision points. For example, in two studies, persons with AD were taken on a route that had cues placed at decision points, such as hallway intersections, and in areas irrelevant for wayfinding. Participants in both studies were able to recall landmarks placed at key decision points more frequently than those irrelevant for wayfinding (Cherrier, Mendez, & Perryman, 2001; Kessels, van Doormaal, & Janzen, 2011). The results of these studies indicate that persons with dementia may benefit from cues placed at destinations and key decision points along a route.

While the literature review uncovered small case studies and theoretical recommendations for wayfinding enhancements of built environments, little research—other than the room recognition studies—was found that specifically examined the most effective type and placement of wayfinding cues for persons with dementia. There also is a lack of systematic studies investigating the effect of specific cue properties on wayfinding in persons with dementia. Until the cue properties that best support wayfinding are identified and tested systematically, there will be a lack of support for evidence-based wayfinding interventions for this population.

Study Purpose

The purpose of this study was to examine the effect of salient visual cues on the wayfinding performance of older adults with and without AD, both initially and over time, in a VR simulation of a senior residential community. For this study, salient visual cues were defined as colorful and familiar objects placed at key decision points. The researchers hypothesized that (1) subjects with early stage AD/MCI (mild cognitive impairment) would take longer to find their way to specified goal locations and find them less frequently than would individuals without AD/MCI, and (2) all subjects would find their way to the goal locations faster and more frequently when salient visual cues were present than when they were not. This study was designed to provide scientific evidence for the effect of salient cues on wayfinding for older adults with and without AD/MCI.

Method

This section includes a discussion of the study's participants (including inclusion/exclusion criteria and screening instruments used to select), procedures, measures, VR platform (virtual senior living [VSL]), and data analysis. The "VSL" section includes a description of how the visual cues were selected and the VSL testing procedures.

Participants

The convenience sample included 88 participants: 38 persons with AD or MCI due to AD in the experimental (AD/MCI) group, and 50 persons without AD or MCI in the control group. The AD/MCI group was recruited via memory clinics, Alzheimer's Association support groups for early stage AD, and recruitment events held at community sites such as senior independent living facilities. The control group was recruited via word of mouth, brochures, and an existing database of community-dwelling older adults who wished to be contacted for research studies.

Several screening measures were used to assess potential participants' medical history and visual abilities. Subjects completed an investigator-designed demographic questionnaire to rule out a history of medical, neurologic, or psychological conditions that could affect their ability to complete the test, such as Parkinson's disease or stroke. To see the VR environment, subjects needed visual acuity of 20/40 with correction (if needed). Therefore, visual acuity was assessed using the Snellen Eye Chart (Frith, Gray, MacLennan, & Ambler, 2001). To test the effect of colorful cues accurately, individuals with color blindness had to be excluded from this study. Accordingly, potential participants were assessed using the Ishihara Color Blindness Test (Ishihara, 1925). Finally, subjects who reported a history of motion sickness were excluded due to the likelihood they would experience simulation sickness during VR testing.

To confirm AD/MCI group participants were in the earliest stages of dementia, they completed the Clinical Dementia Rating (CDR) Scale (Hughes, Berg, Danziger, Coben, & Martin, 1982). The CDR uses subject and informant interviews to gauge potential participants' "memory, orientation, judgment and problem solving, community affairs, home and hobbies, and personal care" (J. C. Morris, 1997, p. 174). The CDR global score ranges from 0 (*no dementia*) to 3 (*severe dementia*). For this study, individuals in the AD/MCI group had CDR scores of .5 (*questionable*) or 1 (*mild*) indicating MCI or early stage AD. In addition, the participants' health care providers were asked to confirm the diagnosis of primary AD or MCI due to AD based on standardized clinical criteria (S. M. Albert et al., 2006; McKhann et al., 1984). Conversely, individuals in the control group had to demonstrate a score of 27 or higher on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) indicating a low likelihood of dementia (O'Bryant et al., 2008).

Of those in the AD/MCI group, 18 were diagnosed with MCI due to AD and 20 were diagnosed with early stage AD. To ensure this study encompassed persons in the early stages of AD, the researchers included persons with both diagnoses. In 2011, the National Institute on Aging–Alzheimer's Association published updated AD criteria and a new category of preclinical dementia called *MCI due to AD* (M. S. Albert et al., 2011). The guidelines indicate that the main difference between AD dementia and MCI due to AD is that persons with AD dementia are expected to have functional disabilities, while persons with MCI due to AD are not. The diagnoses of MCI due to AD and early stage AD may overlap (J. C. Morris, 2012).

Based on an initial power analysis of data from a prior study, the recruitment goal was to have 40 subjects in each group complete all 3 days of study testing. However, 16 subjects (control group, n = 10, 19%; AD/MCI group, n = 6, 12%) withdrew due to simulation sickness, a common side effect of VR testing that causes people to feel dizzy or nauseated (Cobb, Nichols, Ramsey, & Wilson, 1999). Two subjects withdrew for other reasons. Subjects who withdrew reported no adverse effects after stopping the study. Of the subjects who met the inclusion criteria, 40 control group participants and 30 AD/MCI group participants completed all 3 days of testing.

Procedure

In this within-subjects, repeated measures study, the researchers tested wayfinding using a VR wayfinding task with two cue conditions. Interested persons were told about the study over the phone and asked about their willingness to participate. Researchers met with those who agreed to participate in an initial session (Day 1) in their homes or at the testing site based on the subject's preference. During this visit, researchers obtained the individual's informed consent and screened them for inclusion/exclusion criteria. The AD/MCI group participants were assessed for consent capacity using the evaluation to sign consent measure (ESC; Resnick et al., 2007). Informed consent was obtained from all participants who had consent capacity. If the ESC results indicated the individual did not have consent capacity, permission was obtained from the participant's designated decision maker after verbal assent was obtained from the participant. Seven subjects lacked consent capacity based on the ESC (five with AD and two with MCI due to AD) but assented to be in the study with consent from their decision maker.

Testing for Days 2 and 3 took place at the researchers' university laboratory or at a private room in one of three designated community locations. The location was chosen by the participants as some lived in a different city from the laboratory or had difficulty with transportation. The subjects were asked to complete the same exact VR wayfinding task on each of the three study days. All subjects received a US$20 gift card to a local store for each day of testing. Subjects who participated all 3 days received US$60 in gift cards.

Measures

Several cognitive tests were administered to measure differences in cognitive ability between the control group and the AD/MCI group. It was important to compare the two groups to determine cognitive factors that could influence their wayfinding abilities. To prevent testing fatigue, the cognitive tests were spread out over Days 1 and 2.

On Day 1, participants' working memory and attention were assessed as these abilities are related to wayfinding performance (Davis, Therrien, & West, 2009). Researchers used the Digit Span tests that require subjects to repeat gradually longer strings of numbers in a forward order (Digit Span Forward [DSF]) and reverse order (Digit Span Backward [DSB]; Weschler, 1987). Higher scores indicate better attention and working memory. Normal scores are ≥ 5 for DSF and ≥ 4 for DSB (Lezak, 1995). To control for the possible confounding factor of varying levels of computer ability among subjects, computer experience also was assessed on Day 1 via the Computer Use Survey (Moffat, Zonderman, & Resnick, 2001). For this survey, subjects rated their experience in different types of computer use with a Likert-type scale ranging from 0 to 7. Total scores range from 0 (*no experience*) to 21 (*highly experienced in all areas*).

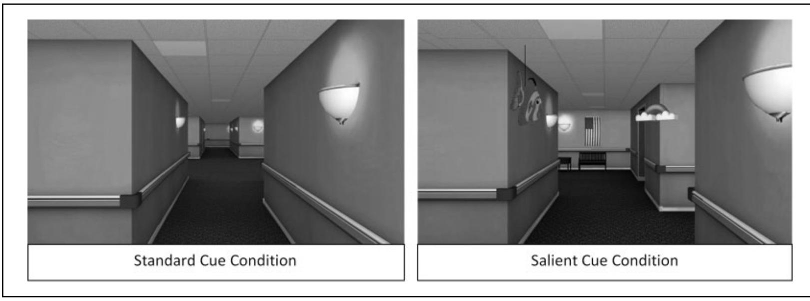

Figure 1. Virtual senior living.
Note. These are screen shots of one hallway in the VSL. The cues in the salient cue condition were bright and colorful (realistic colors). Carpet was a variegated brown; walls were beige. Inset surrounds with apartment doors were blue with wooden doors. VSL = virtual senior living.

On Day 2, the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) was administered to all subjects. This test measures several cognitive domains for a total score of up to 30 points and was used as a general cognitive measure for this study (Nasreddine et al., 2005; Smith, Gildeh, & Holmes, 2007).

VSL

Wayfinding ability was tested using the VSL application, which was developed by the corresponding researcher and the University of Michigan 3D lab. The VSL is a computerized, three-dimensional computer simulation that is based on an actual continuing care retirement facility and displayed on a 12-feet-wide rectangular screen. Subjects navigate through the simulation using a joystick. Subjects can move in any direction within the computerized environment just as if they were walking, but they cannot go through any doors or use elevators.

The VSL has two environments or cue conditions (CC): standard (CC1) and salient (CC2; Figure 1). Each test environment included a goal location that participants were asked to find. In CC1, the goal location was a dining room containing tables and chairs; in CC2, it was a set of open doors leading outside to a large tree. Each cue condition had separate goals, so the participants would know they were in a different part of the facility. The cue conditions were equal in length (each was 285 total feet in length), with the exact same distance from start to goal. Each cue condition had six hallways and required three correct turns to find the goal location (Figure 2). They had the

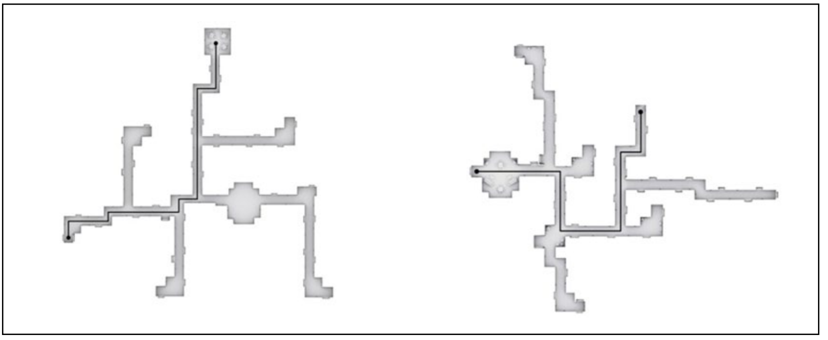

Figure 2. Routes in the virtual senior residence.
Note. These are the floor plans and routes for the standard cue condition (left) and salient cue condition (right).

same number of hallways and distractor (incorrect) hallways. Like the model community, some of the hallways in the cue conditions had jogs; jogs were defined as bends in the hallway that partially limited visual access but did not have an intersection of more than one hallway. Turns were defined as an intersection of more than one hallway requiring a decision of which way to turn. While there was only one correct route to the goal location, if the subjects made a wrong turn, they could re-orient themselves by returning to the correct route at any point along the way.

CC1 was the standard environment, and it replicated the model retirement community with plain walls, muted carpeting, and equally spaced doors. No additional cues, furniture, or signs were present in CC1. The views down hallways were restricted in both environments (as is the case in the actual community) due to hallways that shift slightly right or left. CC2 was enhanced with 10 salient visual cues or large, colorful, and familiar objects located at key decision point along the route as well as at the end point. Cues included a red car model, a model of a rainbow, an large orange fish model, a bunch of red balloons, a picture of children wearing bright clothing, a large red cardinal picture, a bright yellow sun, an orange lion wall rug, a purple butterfly model, and an American flag. The cues could be seen from a distance, and several were three-dimensional making them visible from several vantage points.

Visual cue selection. The cues selected for CC2 were based on the results of two previous VR studies conducted by this study's research team (Davis & Therrien, 2012; Davis, Therrien & West, 2008). In these two studies, the testing environments were VR replicas of the gold-standard Morris water maze task, a spatial learning test used in animal studies (R. G. Morris, 1983; R. G. Morris, Garrud, Rawlins, & O'Keefe, 1982). Study participants were tasked with finding a hidden platform in a computer display of a round room surrounded by four walls that were enhanced with cues. The only way to determine the location of the platform was to remember its location in relationship to the wall cues. The first study tested how fast and frequently older women and younger women found the goal location in four VR mazes with differing cues. Subjects were tested during six learning trials in each maze task. There were four testing environments: one with colorful and stable wall pictures and architectural elements around the perimeter of the maze, one with two small black and white abstract cues, one with black and white line drawings, and one with colorful pictures that moved between trials. The results showed that all subjects found the location more frequently and faster in the environment with colorful and stable cues when compared with the other three environments. The older women, in particular, had problems finding their way in the condition with the two abstract cues. As expected, no subjects could find their way in the condition with the moving cues. The results of the study gave beginning support for color and stability as important cue characteristics for remembering a goal location (Davis, Therrien & West 2008)

In a subsequent study using the same VR platform, the researchers tested the impact of color and familiarity on learning a goal location in a large sample of adults aged 55 to 96. These subjects were tested in four environments with varying pictorial cues: colorful and familiar, colorful and abstract, black and white and familiar, and black and white and abstract. The familiar objects were those that were easily named such as cars and flowers. The abstract conditions had abstract paintings. Results showed that all subjects found the goal location the fastest and most frequently when the cues were colorful and familiar, leading the researchers to conclude that this combination of cue properties was the most effective for learning the goal location (Davis & Therrien, 2012). In the current study, the researchers wanted to test the impact of colorful and familiar cues, similar to those used in the previous studies, but in a VR environment lifelike and representative of a senior living community.

VSL testing procedure. Subjects were first oriented to moving within the VR environment using a joystick until they were comfortable doing so and demonstrated their understanding of how to move accurately. They then had to complete two timed joystick tests in which they had to reach a specified destination within 30 s. If they were unable to pass the joystick test after two tries, they were withdrawn from the study. If they passed the joystick test, they moved on to VSL testing. The joystick test was used to confirm that performance in the VSL could be attributed to wayfinding ability versus the physical joystick manipulation. Such tests are common in VR research (Moffat et al., 2001).

For the VSL testing, subjects were tested in both CC1 and CC2 for two consecutive days. The order of the cue conditions was alternated between participants so that each cue condition had an equal chance of being first (see online appendices for Table S1 for a description of the procedure). The next day, subjects returned and completed the same wayfinding task (the order of the cue conditions was reversed), for 10 more trials (five in each cue condition). Thus, subjects were tested 10 times in each cue condition for a total of 20 trials over 2 days.

Data Analysis

The VSL produced several variables of wayfinding performance, including whether the desired destination was found and the time required to find it. The time needed to find the destination is a common measure of learning in VR tests (Moffat et al., 2001; Zakzanis, Quintin, Graham, & Mraz, 2009). As subjects learn the desired destination, they should show shorter trial times as they navigate more directly to it. Testing over multiple trials simulates, in part, multiple exposures to an environment that one might experience over time. Testing over multiple days allows researchers to assess participants' recall (memory) and gives participants more learning opportunities which are important for older adults (Davis & Therrien, 2012).

SPSS version 20 was used to analyze the data. Demographic characteristics and cognitive variables were compared between subject groups using *t* tests and chi-square tests. Linear mixed models (LMMs) were fitted to the data using time to the goal location in seconds as the dependent measure of wayfinding performance. The independent variables in this analysis include day of VSL testing (1 or 2), trial (1 through 5), cue condition (standard or salient), gender, age, group, and computer experience scores. The main effects, along with all two- and three-way interactions between the independent variables, were tested for significance in each model. Non-significant interactions were removed one at a time until the best fitting and parsimonious model was achieved. Significance of the whole model and of the fixed effects was set at $p < .05$.

In addition to the LMM analysis, independent-samples *t* tests and paired *t* tests were used to determine whether the number of goal acquisitions differed among days, groups, and cue conditions. Goal acquisitions were defined as positive (finding the goal) or negative (not finding it) attempts within each 3-min trial, with a maximum score of five goal acquisitions per cue condition for each day of testing. Subjects could score a possible 0 (*did not find the goal location at all*) to 10 (*found goal in all 10 trials over 2 days*) per cue

Table 1. Comparison of Demographic and Cognitive Variables Between Subject Groups.

Demographic variable	Control group (n = 50)	AD/MCI group (n = 38)	t (df)	Chi square (df)	p value
Age, M (SD)	75.46 (5.25)	77.26 (6.73)	−1.41 (86)		.162
Education, M (SD)	16.05 (2.75)	15.47 (3.21)	0.91 (86)		.368
No. of medications, M (SD)	6.82 (4.55)	6.13 (3.54)	0.77 (86)		.443
Gender					
Male, n (%)	18 (36)	19 (50)		1.74 (1)	.188
Female, n (%)	32 (64)	19 (50)			
Non-White, n (%)	3 (6)	0 (0)		2.36 (1)	.255
Financially stable, n (%)	48 (96)	35 (92)		0.61 (1)	.434
MMSE, M (SD)	29.16 (0.99)	25.87 (3.01)	7.25 (86)		<.001
MoCA, M (SD)	25.64 (2.09)	18.97 (3.58)	10.90 (85)		<.001
DSF, M (SD)	6.12 (0.96)	5.97 (1.09)	0.67 (85)		.508
DSB, M (SD)	4.50 (1.18)	4.14 (1.16)	1.43 (85)		.155

Note. AD = Alzheimer's disease; MCI = mild cognitive impairment; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; DSF = Digit Span Forward; DSB = Digit Span Backward.

condition for a total of 20 trials. Significance of these analyses was set at $p < .005$ after Bonferroni correction for multiple tests.

Results

The sample characteristics are presented in Table 1. No significant differences between the control group and AD/MCI groups were found with respect to age, education, number of medications, gender, race, socioeconomic status, or digit span scores. As expected, there was a significant difference between the groups' MMSE and MoCA test scores with the AD/MCI group showing more cognitive impairment. Differences between those who withdrew from the study (n = 18) and those who did not (n = 70) were analyzed, and no significant differences were found in any of the demographic or cognitive variables.

Wayfinding Performance

The first hypothesis—that the control group would find their way faster in the VSL than the AD/MCI group—was supported by the data. The control

Table 2. Linear Mixed Model Type III Tests of Fixed Effects: Time to Find the Goal Location.

Variable	*df*	*F*	Significance (*p* values)
Intercept	1, 84	3,983.29	<.001
CC	1, 390	45.40	<.001
Day	1, 385	114.59	<.001
Trial	4, 987	91.02	<.001
Gender	1, 84	2.10	.151
Group	1, 85	149.96	<.001
CC × Day	1, 381	1.48	.225
CC × Trial	4, 986	.25	.910
Day × Trial	4, 987	6.05	<.001
Day × Gender	1, 408	4.32	.038
Day × Group	1, 386	9.73	.002
Trial × Gender	4, 987	2.68	.034
Trial × Group	4, 987	16.86	<.001
CC × Day × Trial	4, 986	2.53	.039
Day × Trial × Group	4, 987	8.05	<.001

Note. CC = cue condition.

group found their way to the goal destination faster than the AD/MCI group in both cue conditions. The LMM analysis (Table 2) showed a significant interaction among group, day, and trial, $F(8, 987) = 8.05$, $p < .001$ (Figure 3), indicating that the subjects in the control group found their way faster over days and trials in both cue conditions when compared with the AD/MCI group. The steepest learning curve was seen by the control group on the first day of testing, as evidenced by the differences between Trials 1 and 5. Of note, learning occurred by both groups on both days of testing, as evidenced by improved times to reach the goal location between Trials 1 and 5.

The mean number of goal acquisitions for both conditions combined (the maximum number of times to find the goal location was 20 times) was significantly different between the groups, with the control group finding the goal significantly more often ($M = 16.1$, $SD = 2.23$) than the AD/MCI group ($M = 6.45$, $SD = 5.43$), $t(68) = 25.81$, $p < .001$ (Figure 4). The mean number of goal acquisitions was compared between groups on Days 1 and 2 of testing using an independent-samples *t* test. Results showed that the control group found the goal location significantly more often than the AD/MCI group in both cue conditions, on both days, and overall (Figure 4).

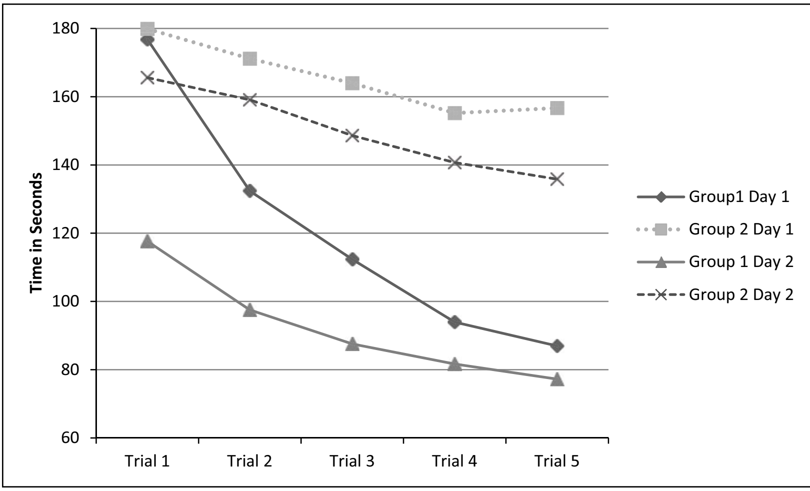

Figure 3. Estimated marginal means for Group × Day × Trial interaction.
Note. Group 1 = control; Group 2 = AD/MCI. This graph shows the effect of group within days and trials for both cue conditions combined. There was a significant difference between the groups on both days of testing. AD = Alzheimer's disease; MCI = mild cognitive impairment.

Effects of Salient Visual Cues

The second hypothesis that both the control and AD/MCI groups would find their way more often and faster in the salient cue condition was supported by the data. The LMM analysis showed an interaction among cue condition, day, and trial, $F(4, 986) = 2.53$, $p = .039$ (see online appendices for Figure S1), with subjects finding the goal location the fastest in the salient cue condition on the second day of testing. The poorest (longest time) wayfinding performance was in the standard condition on Day 1. Performance on the second day of testing was better in CC2 than CC1, indicating better recall over time.

Paired-samples *t* tests were calculated to compare the mean goal acquisitions in the standard and salient cue conditions for each day of testing (Table 3). Both groups had more goal acquisitions and a faster time acquiring the goal in the salient cue condition compared with the standard cue condition on both days of testing.

Other Findings

There is evidence in the literature that males have an advantage in spatial learning tasks (Chen, Chang, & Chang, 2009) and are less dependent upon cues than

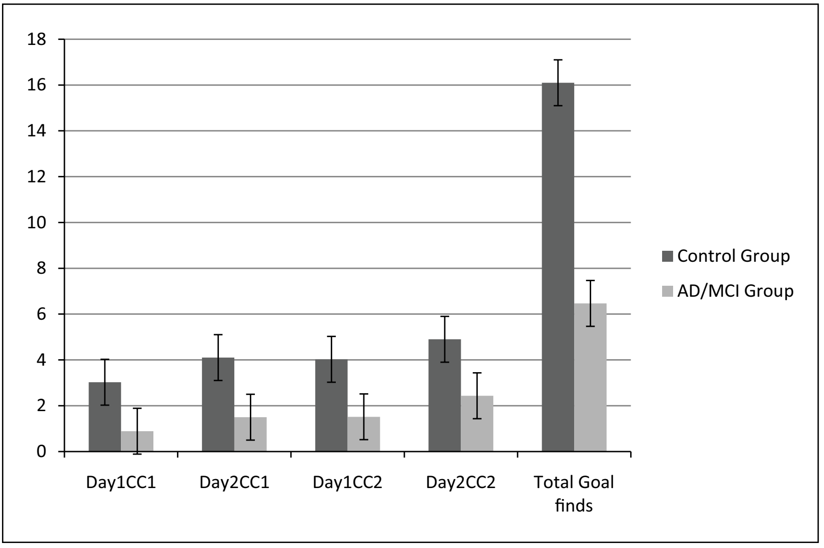

Figure 4. Comparison of goal acquisitions between groups.
Note. Error bars reflect the standard error of the mean. The *t* tests compare goal acquisitions between the groups. Comparison of mean goal acquisitions between groups: Day1CC1: $t(74) = 7.974$, $p < .001$; Day2CC1: $t(51) = 7.19$, $p < .001$; Day1CC2: $t(34.50) = 8.71$, $p < .001$; Day2CC2: $t(31) = 7.65$, $p < .001$. Total target finds: $t(36) = 9.16$, $p < .001$. AD/MCI = Alzheimer's disease/mild cognitive impairment; CC1 = standard cue condition; CC2 = salient cue condition.

are females (Chen et al., 2009; Schmitz, 1999); thus, gender was included as a variable in the study. In the control group, there was no significant difference in the mean age of males ($M = 76.28$, $SD = 5.93$ years) compared with females ($M = 75$, $SD = 4.87$), $t\,(48) = .823$ $p = .415$. In addition, there was no significant difference in the age of males ($M = 77.47$, $SD = 6.05$) and females ($M = 77$, $SD = 7.39$) in the AD/MCI group, $t = .222$, $p = .825$. The results from the LMM showed a day-by-gender interaction, $F(1, 408) = 4.32$, $p = .038$, with males finding the goal significantly faster (estimated marginal means [EMM] = 137.79 s) than did females (EMM = 148.07 s) on Day 1, $F(1, 119) = 5.11$, $p = .026$. There was no significant difference between males (EMM = 120.20 s) and females (EMM = 122.07 s) for time to find the goal location on Day 2, $F(1, 132) = 0.154$, $p = .696$. The LMM also indicated a significant trial-by-gender interaction, $F(4, 986) = 2.617$, $p = .034$, with post hoc analysis using Bonferroni correction showing that males were significantly faster on Trial 3 (both days combined; EMM = 121.21 s) when compared with females (EMM = 135.04 s), $F(4, 194) = 13.806$, $p = .009$ (see online appendices for Figure S2).

Table 3. Comparison of Goal Acquisitions Between Salient and Standard Conditions.

Goal acquisitions	Standard, *M* (*SD*)	Salient, *M* (*SD*)	*t* (*df*)	*p* value
Control group, Day 1	3.08 (1.10)	4.03 (0.48)	−5.11 (39)	<.001
Control group, Day 2	4.10 (1.22)	4.90 (0.38)	−3.94 (39)	<.001
Control group, total	7.18 (2.12)	8.92 (0.66)	−5.02 (39)	<.001
AD/MCI group, Day 1	0.94 (0.12)	1.52 (1.55)	−2.23 (30)	.029
AD/MCI group, Day 2	1.50 (1.68)	2.53 (2.74)	−3.36 (30)	.001
AD/MCI group, total	2.47 (2.74)	4.00 (3.09)	−3.92 (29)	.001

Note. Paired *t* tests were conducted to compare mean goal acquisitions between the salient and standard cue conditions. Bonferroni adjustments were done to correct for multiple comparisons, with $p < .005$ as significant. AD = Alzheimer's disease; MCI = mild cognitive impairment.

Discussion

The most important finding from this study was that wayfinding ability for persons with and without AD/MCI was positively affected by the presence of colorful and familiar visual cues placed at key decision points. All subjects found their way faster and more often in the salient cue condition than in the standard condition. The learning curve was the steepest (most favorable) in the salient cue condition on Day 1, showing that salient cues had a strong effect on learning. In addition, the subjects had better recall on Day 2 of testing in the salient cue condition compared with the standard cue condition, indicating salient cues helped improve participants' memory over time.

These study results support those of other studies indicating that persons with AD/MCI have impaired wayfinding abilities (Algase et al., 2004; Caspi, 2014; Chiu et al., 2004; Kessels, Feijen, & Postma, 2005; Marquardt & Schmieg, 2009; Pai & Jacobs, 2004; Rowe, 2003). While the AD/MCI subjects in this study were in the early stage of the disease (CDR = .5-1), on average, they found their way only 32% of the time, compared with 81% of the time for the control group. The AD/MCI subjects took an average of 50 s longer to find their way than the control subjects in both environments, indicating that there is a substantial degree of wayfinding impairment for persons early in the disease process.

The finding that salient visual cues helped all subjects find their way is promising and supportive of Lawton's environmental press theory. The long, plain corridors in our VR environment, so common in many facilities for the aged, have a high degree of press, as they are confusing and hard to differentiate. One administrator at the VSL model facility commented on the problem of getting lost in the maze of hallways by saying, "We don't call them residents until they are lost at least once." Our study results support the findings of others studies that indicate long hallways and monotonous designs make it especially difficult for persons with dementia to learn and find their way (Marquardt, 2011; Netten, 1989; Passini et al., 2000; Passini et al., 1998). The colorful and familiar cues used in this study, which were designed to be perceptually and cognitively salient (Caduff & Timpf, 2008), may have reduced the environmental press by making the formerly monotonous hallways and decision points easier to differentiate and remember.

The use of a VSL residence proved to be an effective and ecologically appropriate tool for measuring wayfinding. Although VR environments lack real-world elements, there are advantages in using them for testing. In the real world, it can be difficult or impossible to control extraneous variables that affect wayfinding performance such as noise, light, and interruptions. VR environments allow all subjects to be tested in identical environments so that specific environmental or test characteristics can be isolated and studied. In addition, persons with mobility impairments can be tested repeatedly over trials without the physical burden of real-life testing (Bainbridge, 2007; Davis, 2009). VR testing allows for active, independent exploration of the environment using a joystick (Davis, 2009). Active exploration has been shown to be important for forming a map-like memory of an environment (Carassa, Geminiani, Morganti, & Varotto, 2002). It should be noted that in this study, the learning that occurred in both CC1 and CC2 could have been a result of both active and passive learning. As subjects were virtually taken to the goal by the research assistant after each failed trial, it is possible that the type of learning that occurred was related to passive learning as well as active exploration.

No other studies were found that used a replica of a senior residential environment in a wayfinding task for persons with dementia. However, other researchers have used VR environments with persons with dementia in the form of virtual outdoor environments, virtual cities (Blackman, Van Schaik, & Martyr, 2007; Zakzanis et al., 2009), or virtual water mazes that replicate spatial learning studies done on animals (Davis & Therrien, 2012; Davis, Therrien, & West, 2008; Davis et al., 2009; Kalová, Vlcek, Jarolímová, & Bureš, 2005). The results of extensive research into the validity of VR-simulated environments for wayfinding indicate that wayfinding ability can transfer from a VR environment to the real-world environment after which it was modeled (Foreman, Stanton-Fraser, Wilson, Duffy, & Parnell, 2005; Wilson, Foreman, & Tlauka, 1997). In addition, the brain areas used for wayfinding have been shown to activate during navigation in VR environments (Grön, Wunderlich, Spitzer, Tomczak, & Riepe, 2000; Parslow et al., 2004).

These results also were congruent with those of many other studies indicating that performance of males on wayfinding tasks is often superior to that of females (Chen et al., 2009; Davis & Therrien, 2012). Males found their way overall better than did females on the initial day of testing and were significantly faster at finding their way in Trial 3. The results did not indicate a gender-by-group effect in that the gender differences were consistent across groups and not affected by AD/MCI. Interestingly, the females were comparable with males by the last study trial (see online appendices for Figure S2), indicating that the gender advantage may be lessened over time with practice.

Limitations

This study had several limitations. While the subjects with MCI due to AD and early stage AD were combined, separating them may have allowed the results to confirm the expected decline in wayfinding abilities that accompanies the disease process (Benke, Karner, Petermichl, Prantner, & Kemmler, 2014; Man-Son-Hing, Marshall, Molnar, & Wilson, 2007). The groups were combined because their demographics were not statistically different. However, the similar demographics might be attributed to the small sample size produced when the groups were divided. In addition, researchers were able to test persons in the VR environment over only 2 days. A longer exposure to the virtual environment might have resulted in continued learning, as subjects' learning improved until the final trial.

We made every effort to make the VR environments as similar as possible while providing enough differentiation not to be confusing; however, there may have been some unmeasured differences that could have affected performance. Environmental factors such as visual access have been shown to be important for wayfinding (Baskaya, Wilson, & Ozcan, 2004); it is possible that differences in visual access caused by jogs or turns were sufficiently different between the environments to impact wayfinding performance. The final limitation was the number of subjects that withdrew due to simulation sickness, a common side effect of VR studies. The subjects' vulnerability due to advanced age and diminished cognitive ability resulted in the researchers withdrawing persons at the first sign of symptoms. A post hoc analysis of withdrawals did not indicate a pattern related to the presence of dementia or any other demographic variables.

Future Studies

Using salient visual cues to improve wayfinding is an inexpensive, potentially effective intervention that can be implemented and tested in existing facilities.

In this study, only the *effects* of the cues were tested. In other words, the cues were not mentioned or taught to the subjects. It is possible that adding other interventions—such as providing education for the cues, practice with them, and longer exposure (more days) to them—could improve the participants' wayfinding to an even greater degree. Therefore, such interventions should be the focus of future research. Educational interventions have been shown to be effective in helping persons with dementia attain certain wayfinding tasks such as using a map and existing landmarks to find a location (McGilton, Rivera, & Dawson, 2003). The effectiveness of improving wayfinding by combining this type of educational intervention with salient visual cues should be studied. In addition, future research should systematically test the use of colorful and familiar visual cues in real-world, long-term care settings. Future studies aimed at determining the impact of other visual cue properties, such as size and texture, on wayfinding also could be beneficial. Finally, other types of cues, such as auditory and tactile prompts, should be tested to determine their contribution to wayfinding in this population. It is possible that as cognition declines in diseases like AD, the properties of cues that assist with wayfinding will need to be adjusted (i.e., made larger, brighter, or more salient).

Conclusion

The environment has a profound effect on the quality of life, health, and well-being of individuals in residential settings. Based on the findings from their study, Volkers and Scherder (2011) concluded that institutional living is associated with low engagement and cognitive decline. A fundamental need of this population is living in a supportive, dementia-friendly community where they know their location and can independently find social activities, dining areas, restrooms, and their bedrooms. This study gives evidence that colorful and familiar visual cues have promise as an intervention to improve wayfinding for persons with AD/MCI. Study subjects with AD/MCI demonstrated a profound decline in wayfinding competence when compared with cognitively normal older adults, indicating that wayfinding impairments begin early in the disease. Both cognitively normal and AD/MCI subjects had improved wayfinding with the presence of the salient visual cues compared with the standard environment. These results provide a beginning foundation for future work, including translating the findings derived from VR into real-world applications.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Research reported in this publication was supported by the National Institute On Aging of the National Institutes of Health under Award Number R15AG037946. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. In addition, this study received funding from Grand Valley State University and Sigma Theta Tau Kappa Epsilon chapter.

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