The Effects of Age on Featural and Geometric Cue Use During Reorientation in an Immersive Virtual Reality Environment

by

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Abstract

This study examined the effects of age on the use of featural and geometric cues for reorientation – the first step of navigation. This study used a three-dimensional Virtual Reality (VR) spatial reorientation task as well as traditional assessment tests to examine cognitive skills and computer usage. Participants received training to find a target location in a rectangular room (geometry) with distinctive objects situated at each corner (features) and were subsequently presented with tests selectively manipulating these cues. Results suggest age may affect adults' ability to incidentally encode geometry, as well as their ability to use distal featural information. Performance on the assessment tests was not related to the use of geometric or featural cues in the VR task, although familiarity with computers may facilitate cue use. These results are important as they suggest geometry, the foundation of our spatial representation, may be selectively affected by age.

To my Oma, my foundation of everlasting love and support.

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Many cognitive abilities decline during the process of aging, and this is particularly salient with spatial cognition. Spatial cognition includes the ability to navigate, which requires efficient processing of spatial information from the environment. As our population ages, it is increasingly important to address the needs of older individuals. The population of older adults in steadily growing, expecting to reach nearly a quarter of the total population by the year 2041 (Kembhavi, 2012), and thus the need to study the effects of aging on cognition is of critical importance. A decline in spatial navigation can have substantial impact on one's life, especially among older adults, which puts stress on the individual as well as caregivers, family, and friends. Research examining decline in navigation ability is important as it can lead to creating more age-friendly environments for older adults, allowing for a more independent daily life.

Previous studies have focused on age-related spatial decline during navigation, including examining whether age affects the initial stage necessary for navigation, orientation (Moffat, 2009; Newman & Kaszniak, 2000). Orientation refers to the process of determining one's position within an environment. Many types of environmental cues have been shown to be used for orientation (Cheng, Huttenlocher, & Newcombe, 2013). Cheng (1986) first examined reorientation using rats and found they were able to use both the shape of the environment, which provided geometric information, and landmarks, which provided featural information, to locate a target location. Geometric information is generally defined as the distance and directional information between objects or, from the shape of an environment itself, such as the shape produced by the walls of an enclosure (Chai & Jacobs, 2009; Margules & Gallistel, 1988; Sturz, Forloines, & Bodily, 2012). Featural information is generally defined as the properties of objects or surfaces within the environment, such as their color, pattern, or texture (Ratliff & Newcombe, 2008a; Sutton, Joanisse, & Newcombe, 2010). These two visually-based cues are also important for orientation by humans (Cheng & Newcombe, 2006).

From a developmental perspective, research has shown that younger children do not encode features but rather rely exclusively on geometric information to reorient (Hermer & Spelke, 1994; Newcombe, Ratliff, Shallcross, & Twyman, 2010). It is not until around age three, that features become integrated into the spatial representation (Newcombe et al., 2010), such that young children and adults can use geometry and featural cues equally well for reorientation (Gouteux, Vauclair, & Thinus-Blanc, 2001; Newcombe et al., 2010). However, more recently research suggests that young children, under the age of two, may be able to use featural information (Learmonth, Newcombe, & Huttenlocher, 2001). This research has focused on the cue-reliability, the probability that a given cue predicts some outcome in the environment. Lyons and colleagues (2014) found that cue-reliability is a dominant factor affecting children's reorientation ability, as children show decreased use of feature cues during a low cue reliability condition compared to a high cue reliability condition. A cue can be considered to have high reliability if it is correlated with the target location in the environment, whereas a cue that is uncorrelated with the target location is considered unreliable (Jacobs, 2002). Thus, it is possible that results from earlier studies, showing children cannot use feature cues to reorient, may have been using feature cues that were of low reliability, such as during the Hermer and Spelke (1994) study in which researchers used a toy brought from participants' homes as the feature cue, which was uncorrelated with the target location in the study environment.

Recently, research has begun to focus on examining the effects of aging on the use of featural and geometric cues during reorientation. There is evidence that the use of featural information may diminish with age, as adults between the ages of 47 – 67 show decreased performance in landmark recognition tasks compared to younger adults (Liu, Levy, Barton, & Iaria, 2011). Additionally, research has shown that there are also age-related deficits on the use of geometric cues during orientation, as adults over the age of 65 years, did not use external room geometry cues to aid navigation (Moffat & Resnick, 2002). Overall this previous research supports that the use of featural and geometric cues changes across the lifespan. Thus, my current study aimed to understand how the process of aging affects the use of featural and geometric cues for reorientation using in an immersive 3-Dimensional (3D) Virtual Reality Spatial Reorientation task (VRSR).

Studies examining the neurological mechanisms supporting reorientation have shown that in addition to it's role in memory processing, the hippocampus is also an important brain structure for navigation (Burgess, Maguire, & O'Keefe, 2002; Grön, Wunderlich, Spitzer, Tomczak, & Riepe, 2000; Maguire, Burgess, & O'Keefe, 1999; Maguire, Frackowiak, & Frith, 1997). Research examining lateralization of function has shown that the two hippocampi processes information differently, with the right hippocampus being responsible for episodic memory and the left for semantic memory (Maguire et al., 1997). It is also known that there are hemispheric differences in spatial processing. Burgess, Maguire and O'Keefe (2002) complied a review of studies using virtual reality examining the role of the hippocampus in spatial memory. Overall the results revealed the right hippocampus is involved in memory for locations within an environment, whereas the left hippocampus is more involved in context-dependent episodic or autobiographical memory. Animal research has revealed that hippocampal volume increases with increased use of spatial memory (Smulders, Sasson, & DeVoogd, 1995) and these morphological changes in the brain in response to extensive navigation experience have also been shown in humans. London taxi cab drivers must go under extensive training, learning how to efficiently navigate between places in the large city which makes them ideally suited for navigation experience research. One study investigating the effects of navigation experience on hippocampal volume examined London taxi cab drivers, considered to be highly experienced in navigation ability, in comparison to control participants who did not drive taxis, considered to have average experience in navigation ability. It was found that right hippocampal volume significantly correlated with the amount of time spent as a taxi driver (Maguire et al., 2000). Furthermore, it was found that when London taxi cab drivers were asked to recall routes, signification activation was seen in the right hippocampus but not the left (Maguire et al., 1997). Together these results suggest that the right hippocampus is particularly involved with geometric information processing, whereas the left is involved with featural information processing. In terms of effects of age, previous research has shown that both left and right hippocampal volumes decrease over time (Driscoll et al., 2003; Jack et al., 1998; Moffat, Kennedy, Rodrigue, & Raz, 2007) and there is evidence of decreased activation in this region particularly for adults over the age of 60 (Moffat, Elkins, & Resnick, 2006). It is possible that geometric information is affected differently by the aging process as research examining adults over the age of 65 has shown decreased activation in the hippocampus and associated decline in the ability to use geometric information during spatial tasks (Moffat et al., 2006; Moffat & Resnick, 2002). As there is evidence to suggest that the hippocampus is an important structure for orientation and that hippocampal volume declines with age, my study investigates whether featural and geometric cue use during reorientation in a virtual environment is affected in adults over the age of 60.

To better understand how young and older adults use featural information, I focused on investigating whether age affects the use of featural information, when presented alone without geometry, when the featural cue information is presented at a distant from the goal location, as well as when featural information conflicts with geometric information. Previous research examining the use of featural information at different distances from the target location has shown that adults have flexibility of feature cue use. Adults were able to locate a target location by using feature cues close in proximity to the target, as well as at a distance from the target (Kelly & Bischof, 2008; McGregor, Good, & Pearce, 2004). However, there is little known about how the use of distal featural information changes with age. Therefore, one purpose of my research was to better understand how age affects the use of featural cues, in particular the use of featural cues distal to the goal location, during a reorientation task.

Incidental encoding of geometry refers to the ability to encode geometric cues in an environment, typically when there are distinctive features present, and use that geometric information to successfully navigate to the goal location, regardless of the presence or absence of features (Doeller & Burgess, 2008). The effect of aging on the incidental encoding of geometric information is an important subject of research, as studies examining the hippocampus have supported its role in encoding of geometric information (Epstein, 2008; Epstein, Harris, Stanley, & Kanwisher, 1999; Morgan, Macevoy, Aguirre, & Epstein, 2011). As mentioned earlier, research has shown that normal healthy aging results in decreased hippocampal volume (Jack et al., 1998), and that adults over the age of 65 show deficits in the use of geometric information (Moffat & Resnick, 2002). Therefore, this study aimed to determine better understand the effects of aging on the ability to encode geometric information.

When featural and geometric cues provide conflicting information about the location of a target area, one must decide which cue to rely upon. Research examining reorientation by featural and geometric cues has examined this type of situation to better understand whether adults show a preference or differential reliance on these spatial cues (Kelly & Bischof, 2005, 2008; Ratliff & Newcombe, 2008b; Sturz & Diemer, 2010). Generally, this research supports that adults weigh featural cues more heavily than geometric cues when the cues are in conflict (Sandstrom, Kaufman, & A. Huettel, 1998). Studies that have examined cue competition have shown that young children shown a strong reliance on featural information compared to geometric information, with this reliance on featural information continuing into adulthood (Kelly & Spetch, 2004; Lee, Shusterman, & Spelke, 2006; Lourenco, Addy, Huttenlocher, & Fabian, 2011; Ratliff & Newcombe, 2007). Therefore, the current study investigated whether age affects adults' use of featural and geometric cues when the cues provided conflicting information regarding the goal location.

Spatial navigation not only involves orientation but also several other processes, such as attention, perception, mental imagery, and decision-making (Berthoz & Viaud-Delmon, 1999). Therefore, my current study used a select assortment of assessments to gain general knowledge regarding these other spatial processes involved in navigation, in addition to the reorientation information collected from the VRSR. The Montreal Cognitive Assessment (MoCA) was used to evaluate various cognitive abilities, such as memory and language. Low performance on the MoCA can indicate mild cognitive impairment which, along with aging, has been shown to affect orientation ability (Davis & Weisbeck, 2016; Marquardt, 2011; Moffat, 2009). I predicted that performance on the MoCA would be correlated with performance on the VRSR task which would suggest that performance on the MoCA could predict spatial cue use.

Another assessment used was a mental rotation test, examining the ability to mentally rotate an object shown from a different viewpoints, as previous research has suggested that mental rotation ability is correlated with performance during spatial tasks (Astur, Tropp, Sava, Constable, & Markus, 2004; Moffat, Zonderman, & Resnick, 2001). Shepard and Metzler (1971) were the first to show that adults are able to mentally rotate a sample object to determine which of the alternatives are the same object but shown from a different viewpoint. Mental rotation ability has been shown to be correlated with some navigation-related abilities such as route knowledge, perspective-taking, maze learning, and the ability to form a cognitive map of the environment (Iaria, Palermo, Committeri, & Barton, 2009; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006; Moffat et al., 2001) as well as performance on other types of navigation tasks such as radial arm maze and Morris water maze (Astur et al., 2004). However, it is not yet known if mental rotation is related to the ability to reorient in a virtual environment. Mental rotation ability is thought to be a process performed by the right posterior parietal lobe (Harris et al., 2000), a structure that has also been linked to aging effects on navigation (Lithfous, Dufour, & Després, 2013; Meulenbroek, Petersson, Voermans, Weber, & Fernández, 2004; Moffat et al., 2006). There is also some evidence that older adults show decreased accuracy and higher error rates in mental rotation tasks in comparison to younger adults (Dror & Kosslyn, 1994; Hertzog & Rypma, 1991). I predicted that performance on the mental rotation test would be correlated with performance on the VRSR task.

Attention and working memory is also known to decline with age (Chao & Knight, 1997; Tse, Balota, Yap, Duchek, & McCabe, 2010; West, 2004). One established assessment for examining attention and working memory is the Digit Span test. This test has been used in previous orientation research, as a measure of short-term memory and attention/concentration

(Guariglia & Nitrini, 2009; Moffat et al., 2001; Parsons et al., 2004), as well as aging research, as short-term memory and attention/concentration are affected by age, which can be seen by decreased in performance on the test by older adults (Grégoire & Van der Linden, 1997; Hester, Kinsella, & Ong, 2003; Sun et al., 2005). I predicted that performance on the digit span test would be correlated with performance on the VRSR task.

As my current study used a VR paradigm, it was also important to gather information regarding participants' computer skills, as previous research has shown that video game skills may influence spatial abilities (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Spence & Feng, 2010). Video game experience has been shown to induce changes in certain cognitive processes such as attentional visual field, multiple object tracking, and visuomotor coordination and speed (Spence & Feng, 2010). Additionally, individuals described as expert gamers (those who played seven or more hours of video games per week for the past two years) differed in cognitive skills such as visual short-term memory and mental rotation compared to non-gamers (Boot et al., 2008). Therefore, I used a modified survey to gather general information regarding computer and video game ownership, as well as skill level for these activities, by my participants. I expected that information gather from the SSRA would reveal correlations between computer usage, video game usage and performance on the VRSR.

Men and women may use spatial cues differently (Linn & Petersen, 1985). One of the most common and largest sex differences among spatial abilities is noted in mental rotation. Previous research has shown sex differences in mental rotation are evident at an early age (Quinn & Liben, 2008) and that men perform more accurately than women (Astur et al., 2004; Linn & Petersen, 1985; Nardi, Meloni, Orlandi, & Olivetti-Belardinelli, 2014). Overall, the evidence of sex effects during spatial navigation are mixed. One study revealed there may be sex differences in spatial learning and memory (Rizk-Jackson et al., 2006). A study examining sex effects in orientation suggests that there are sex differences in orientation and that working memory is an important factor to consider (Moffat, Hampson, & Hatzipantelis, 1998). Previous spatial research examining sex differences in orientation ability suggests that these differences in orientation ability are more specifically related to visuo-spatial working memory differences between men and women, as men perform better on tasks that require the use of visuospatial working memory, such as the mental rotation test (Garden, Cornoldi, & Logie, 2002). Additionally, there is evidence that sex differences in orientation may be due to different navigation strategies employed by men and women; Men rely on a global, geometric cues whereas women rely on landmarks or featural cues (Coluccia & Louse, 2004). Therefore, my study also examined if there were sex differences in performance on the assessments, as well as differences in cue use during the VRSR task.

The overall aim of my current study was to determine how adults use geometric and featural information when orientating. To address this question, the main goal of the study was to determine whether older adults use featural cues and geometric cues during an immersive VRSR, and if there were age-related effects in the ability to use these cues. I hypothesized there would be an age-related decline in the ability to encode and use geometry and features. Secondly, the study examined whether aging influences the flexibility of feature cue use, in particular the use of distal feature cues. Based on previous research, I hypothesized that the use of distal features would decline with age. Thirdly, the study explored whether age affected which of the two type of cues adults weighed most heavily when the features and geometry provide conflicting information. Beginning in childhood and continuing in adulthood, previous research has shown a strong reliance on featural information in comparison to geometric information. Therefore, I hypothesized that age would not influence cue weighing, as featural information would be weighed more heavily than geometry regardless of age. In addition, if the ability to encode geometry declines with age as hypothesized, older adults will not experience a conflict of information during the cue-conflict condition therefore, I also hypothesize older adults will show a strong reliance on feature cues in this condition. The study also compared performance on select assessments with performance during the VRSR. I hypothesized that performance on the assessments MoCA and MRT, digit spans measured by the DST, and computer/video game familiarity would be predictive of cue use during reorientation in the VRSR task. Finally, the study examined sex effects and I hypothesized that sex differences would be evident in the MRT and the VRSR task but would be insignificant in the remaining assessments.

Methods

Participants

Neurologically healthy individuals, in the age range of 18 – 30 years, were recruited from the University of Manitoba participant pool, as well as individuals 60 – 80+ years, from multiple sources such as the University of Manitoba, the Riverview Health Centre, the Centre on Aging, senior centres, and associations (n = 120). Participants were grouped in categories according to age: Under 30, 60 – 69, 70 – 79, and 80 + (ns = 35, 40, 19, and 10, respectively). As it was expected to be difficult to recruit older adults, sample size calculations for adults over the age of 60 were completed to create a target number of participants to recruit for effective results. Sample size calculations suggested 49 participants for each Sex (Cochran’s Sample Size). Informed consent was obtained from all participants prior to beginning the experiment.

General Procedure

Upon arrival at the experimental room, participants were seated at a small desk and asked to read and sign an informed consent form. Participants were then asked to complete four assessments. First, the Montreal Cognitive Assessment (MoCA) was completed to evaluate various cognitive abilities, such as memory and language (see description below). Second, a short mental rotation test (MRT) was completed to evaluate the ability of participants to rotate a line drawn object in their mind, allowing them to consider its appearance from another viewpoint (see description below). Third, a modified Survey of Spatial Representation and Activities (SSRA) was used to record general information for each participant including their age, gender, education level, as well as computer and video game usage (see description below). Fourth, the digit span test (DST), a test which measures an individual’s working memory was administered (see description below). After the assessments, all participants completed the 3-Dimensional Virtual Reality Spatial Reorientation Task (VRSR), a procedure to examine whether individuals encode featural and geometric information, and how these cues are used to find a hidden goal. To prepare participants for the VRSR, researchers provided general information about the task, in addition to the task instructions (see description below). The entire testing session lasted one hour. All procedures were approved by the Senate Committee on Ethics in Human Research and the University of Manitoba (#P2016:107).

Assessments

Montreal Cognitive Assessment. The first assessment completed by the participants was the MoCA. Each participant completed the paper-and-pencil test with verbal instructions from the researcher for guidance. The MoCA consisted of tasks aimed to test eight cognitive abilities: visuospatial/executive, naming, memory, attention, language, abstraction, delayed recall, and reorientation. The test was scored out of 30 points and took approximately 10 minutes to complete. The MoCA is most commonly used as screening tool for mild cognitive impairment, with a score of 26 or above being considered normal. However, research has suggested this cut-off (<26) may not accurately represent diverse (culture, age, language, etc.) populations (Freitas, Simões, Alves, & Santana, 2012; Julayanont, Phillips, Chertkow, & Nasreddine, 2013; Rossetti, Lacritz, Munro Cullum, & Weiner, 2011; Waldron-Perrine & Axelrod, 2012). Participants in my study varied with respect to age, race, and education background. Therefore, for my study the MoCA was not used as a screening tool but rather to gather general information about the participants' cognitive abilities.

Mental Rotation Test. The MRT was the second assessment completed by the participants. During my study, participants were given 5 minutes to complete a paper-and-paper version of the MRT which contained 18 items. Each item consisted of an image of a sample line-drawn object presented on the left side of the page, and four alternative line drawn objects presented to the right. Two of the alternative objects were the same as the sample, but shown from a different rotational viewpoint, whereas the other two alternatives were different objects (see Figure 1 for examples). The participants were instructed to determine which of the alternatives were the same as the sample. One point was given for each correct answer (identification of the same object), whereas one point was subtracted for each incorrect answer, for a total possible score of 36.

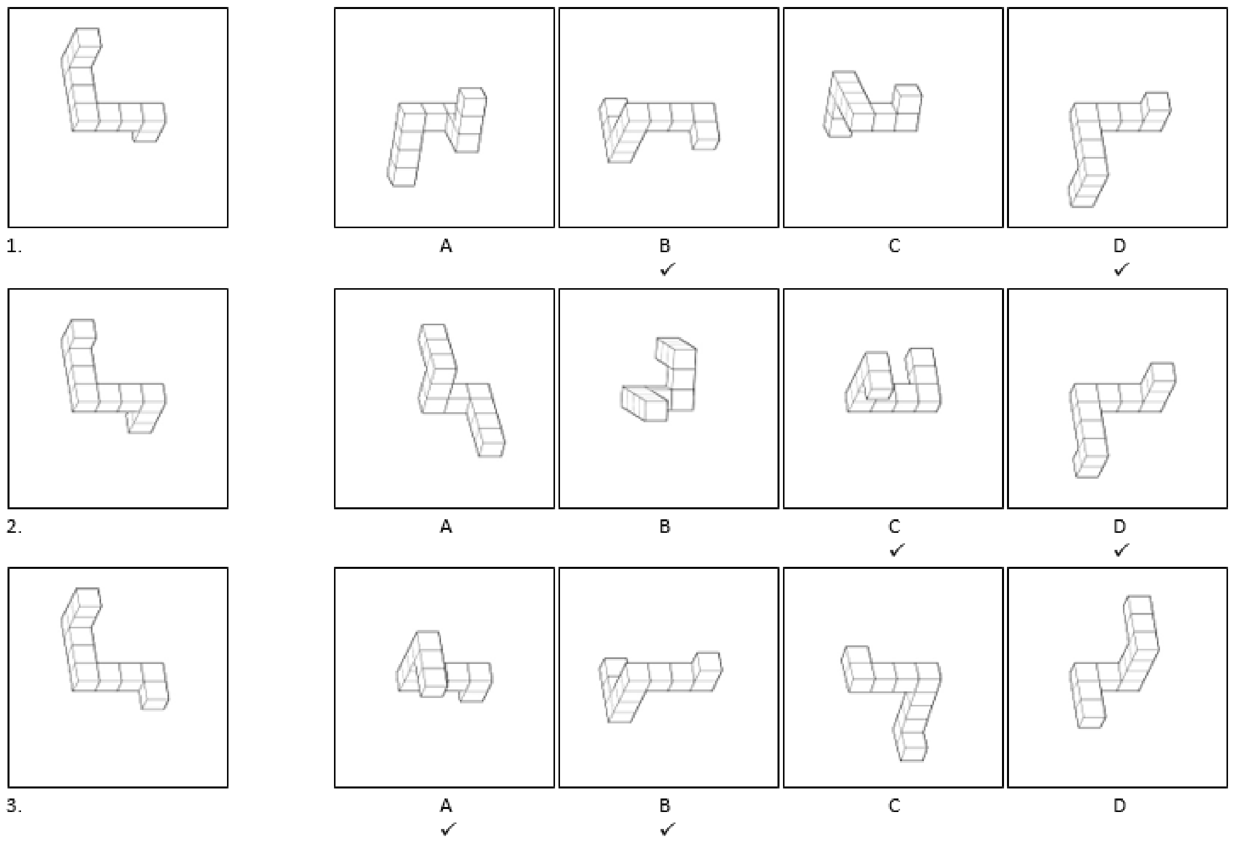

Figure 1. Examples of three items from the MRT. The sample stimulus is shown in the leftmost panel. The comparison images are shown in the rightmost panel (four options). Correct answers are indicated by a check mark (✓).

Survey of Spatial Representation and Activities. Third, participants were asked to complete the modified SSRA, which consisted of 34 questions designed to collect general information regarding spatial navigation, education, computer usage, etc. A combination of multiple choice and Likert-scale responses were required. Questions had been modified from the original SSRA (Terlecki & Newcombe, 2005) to remove sport related questions, and update the computer and video game systems mentioned. Extra self-reported Likert-scale questions were also included to gather additional information regarding spatial navigation. Examples of questions included: ‘How long have you owned/been using a computer?’ and ‘How often do you use a computer?’. Participants were given as much time as necessary to complete the questionnaire. Based on factor analyses from previous research (Terlecki & Newcombe, 2005), answers to the SSRA questions related to ownership of computer, ownership of game systems, frequency of game system usage, and how skilled individuals believed they were at using/playing videogames/game systems were analyzed.

Digit Span Test. The fourth assessment was the DST, which was implemented to examine attention and working memory. The researcher read out a sequence of digits (e.g., 54973) and immediately asked the participant to repeat with the digits in the same order. Six sequences of digits were presented to the participant over 9 blocks. The sequence length in each block increased by one digit from the previous block [two digits during the first block (e.g., 72), three during the second block (e.g., 467), etc., until ten digits during the final ninth block (e.g., 6391727362). Once the participant made more than one error during a block, the test was ended. The participants received a score, referred to as a digit span, for the block during which the participant recalled 5 out of 6 sequences correctly (with potential scores ranging from 2 to 10; this measure provided an index of the participants’ digit span). Note that an auditory version rather than a visual version of the DST was used because previous research has shown that recall performance is better when the sequences are presented orally compared to visually (Crottaz-Herbette, Anagnoson, & Menon, 2004).

Virtual Reality Spatial Reorientation Task

Participants wore an Oculus Rift® virtual reality headset which functioned to visually immerse them in the VRSR environment. The headset contained rotational and positional tracking systems integrated into the electronic display screen to create an immersive 3D experience. A common side-effect from the lack of proprioceptive feedback when using virtual reality is visually induced motion sickness (VIMS), which is characterized by a variety of symptoms such as sweating, dizziness, fatigue, pallor, and/or nausea (D’amour, Jelte, Bos, & Keshavarz, 2017). To eliminate VIMS, which is an important consideration for aging individuals who are particularly susceptible to it (Paillard et al., 2013), participants were seated in a custom-designed wheel chair such that the participant’s movements of the chair in the experimental room correspondingly moved them within the VRSR room (White, Byagowi, & Moussavi, 2015). Participants also were asked to remove the headset between trials (see Methods). It can be noted that out of 120 participants only one participant chose not to complete the VRSR task due to symptoms of VIMS.

The physical experimental room was rectangular (approximately 9 m x 15 m) and large enough to allow the participants to move the wheelchair, permitting them to explore the entire VRSR room, without physically bumping into any walls. The VRSR room was rectangular (3.3 m x 6.87 m x 3 m, virtual units). All four walls were uniform white, floor to ceiling, with no distinguishable directional cues. Lighting was presented uniformly. During training trials, four distinct objects (approximately 0.5 m x 0.5 m x 0.5 m) were present in the VRSR room, one in each corner (herein objects will be referred to as features). The features used in this study were: a yellow cone, a black sphere, a white cube, and a red cylinder (see Figure 2 and Figure 3a).

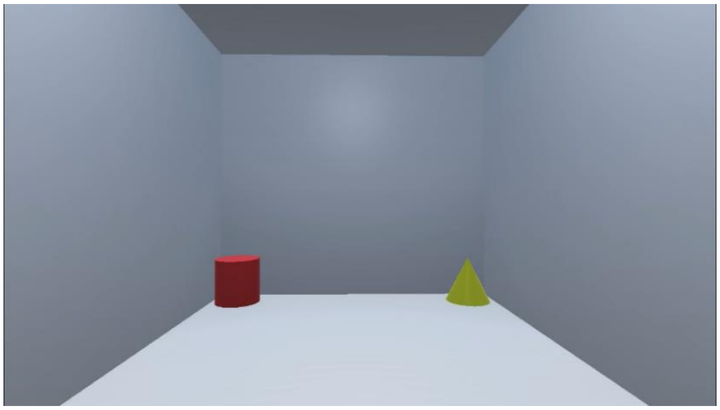

Figure 2. Example image of the VRSR training room, showing two of the four features present during training trials. Note: this image was projected to the headset, such that when viewed, the room and objects were perceived as three-dimensional.

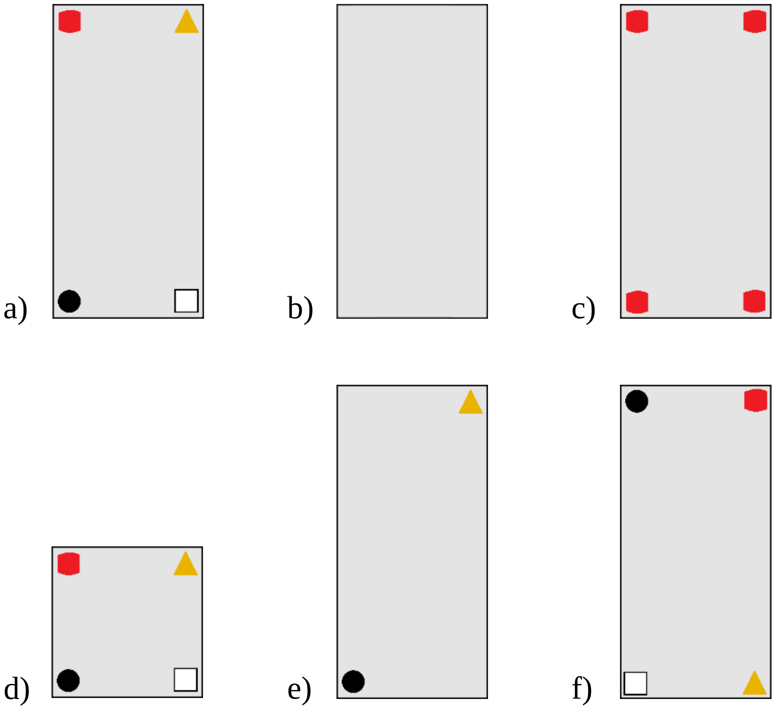

Figure 3. Top-down schematic drawings of the VRSR room during training and test trails. The grey rectangle represents the white room, and the colored symbol at each corner represents the distinctive feature present during each condition. For ease of illustration, in this figure the red cylinder is shown as the reinforced feature (during the study, the reinforced feature was

counterbalanced). a) Training: the four distinctive features were present. b) Geometry-Only condition: the features were removed leaving only the geometric information from the shape of the rectangular room. c) All-Positive condition: the four distinctive features from training were replaced with the reinforced feature from training. d) Features-Only condition: the shape of the room was changed from rectangular to square which removed the informative geometric information, leaving only the features. e) Distal-Features condition: the reinforced feature and its rotational opposite were removed leaving only the two features most distal to the position of the reinforced feature. f) Cue-Conflict condition: the features were moved one corner clockwise, placing the geometric and feature information in conflict.

VRSR Task Set-Up

First, the virtual-reality headset was calibrated to the participant's inter-pupillary distance (the lateral distance between the two pupils) as well as the participant's eye relief (the distance between the headset lens and the corneas). The headset was also adjusted for stability and comfort. Next, participants were told they should shuffle their feet along the floor or use their hands to rotate the wheels, in order to move the wheelchair. This movement would correspond with their movements in the VRSR room. Once participants had confirmed they understood how to move the wheelchair, the task instructions were verbally described (see Appendix A). Participants were asked to remain seated in the wheelchair with the headset in place, after which the researcher moved the participant to the starting position, which was near the center of a larger experimental room. This starting position was used to ensure each participant had sufficient space to move the wheelchair, unimpeded by the walls. Once at the starting position, the researcher gave the participant an electronic button to hold, which was used to initiate each trial and to indicate the participant's corner choice.

VRSR Training Phase

Each participant was pre-assigned a reinforced corner (herein referred to as the "reinforced corner") within the VRSR room. The reinforced corner was counterbalanced across participants. One distinctive feature was positioned in each corner of the VRSR room and remained in the same location during the entirety of the training session. For each participant, the assignment of the reinforced corner remained constant and associated with the same feature (herein referred to as the "reinforced feature") during the entirety of the training phase (i.e., this was a reference memory task). Within the virtual room, the starting position for each trial was centered along one of the four walls facing into the center of the room, with the wall chosen counterbalanced across trails. The participant virtually moved through the VRSR room in search of the reinforced corner. When the participant moved to within a distance of 1.5 virtual units (corresponding to approximately 1.5 m) of the reinforced corner and pressed the electronic button (to indicate a choice), a reinforcement message (e.g., "Good job!") appeared in the headset. If the participant made a choice to any of the other three corners (within a distance of 1.5 virtual units), a negative reinforcement message (e.g., "Wrong") appeared. Otherwise, if the participant was not within 1.5 virtual units when the choice was made, a message (e.g., "Too far from target") appeared and the participant was allowed to make another choice. Prior to the feedback provided during first trial, the participant was not given any information as to the location or properties of the reinforced corner; learning the position of the feature associated with reinforcement required trial-and-error learning. Thus, participants were informed that for the first few trials, they would not know which corner was associated with the "Good job!" message but would need to guess. If their guess was incorrect, they would be provided with an opportunity to continue searching, but their goal was to be as accurate as possible with their first choice. Once the participant located the reinforced corner, they were asked to remove the headset, and the researcher repositioned them back to the starting position within the larger experimental room in preparation for the next trial.

A total of eight training trials were completed by each participant. To meet the criterion of the training phase, the participant had to locate the reinforced corner on the first choice during the last two training trials (trials 7 and 8). If this criterion was met, the participant proceeded to the testing phase (see below). If the criterion was not met after the eight training trials, the participant did not proceed, but rather the experimental session was ended, the participant was thanked for their participation, and was debriefed about the purpose of the study and any questions were addressed by the experimenter.

VRSR Testing Phase

Upon successful completion of the training phase, participants were presented with two blocks consisting of five testing conditions each, for a total of ten testing trials (see below). Testing conditions were presented in a counterbalanced order, with each testing condition selected without replacement within each block. Procedures for testing trials were the same as the training trials, with two exceptions: the participant was only permitted one choice, and a trial ended without a reinforcement message (i.e., all testing trials were non-reinforced – neither the “Good Job” message nor the “Wrong” message appeared). Thus, during the testing trials, once the participant pressed the button indicating a choice, the message “Please move to starting position” appeared, at which point the researcher asked the participant to remove the headset and moved them to back to the starting position within the larger experimental room. At the completion of each block of testing, participants received a reinforced training trial and a non-reinforced training trial (herein referred to as a control trial). These two additional trials allowed for the evaluation of whether the participant's choices remained consistent when presented with the training trials after experiencing the unreinforced testing trials, as conducting trials in extinction may cause participants to alter their responses. Additionally, the inclusion of these trials was used to ensure the participants did not become discouraged after experiencing several trials ending without reinforcement.

Geometry-Only condition. To evaluate whether geometry was encoded, participants searched in the same rectangular room as during training but the four distinctive features in the corners were removed (see Figure 3b). Participants were considered to have incidentally encoded geometry if they limited their searching to the two geometrically correct corners (i.e., the corners with the same properties as the reinforced corner – e.g., short wall on the right, long wall on the left, when considering the corner with the red cylinder as the reinforced corner), and were able to rely on geometry when features were not present. If the participants were unable to limit their searching to the two geometrically correct corners, and instead chose randomly among the four corners, this supported that geometry was not encoded. This condition also served as a control to ensure the participants were not using a cue which was unaccounted for, allowing them to remain oriented (i.e., accurately choosing the goal location), and limit their searching to one corner.

All-Positive condition. During the All-Positive condition, the distinctive features were removed from the room, and replaced with replicas of the participant's reinforced feature during training (see Figure 3c). For instance, if a participant was reinforced for choosing the corner with the red cylinder during training, each of the four distinctive features were now replaced with four identical red cylinders. This manipulation removed all the distinctive featural cues, and similar to the Geometry-Only condition, was used to evaluate whether participants had encoded the geometry of the room during training. If participants limited their searching to the two geometrically correct corners, this supported they had incidentally encoded the geometry during training. Previous research has shown that by including the reinforced feature (even though uninformative) participants are able to make more geometrically correct choices than during the Geometry-Only condition, suggesting the presence of the reinforced feature cue may facilitate geometric encoding (Graham, Good, McGregor, & Pearce, 2006; Horne & Pearce, 2011; Kelly, 2010).

Features-Only condition. To evaluate whether participants would be able to encode featural cues in the absence of geometry, the room shape was modified from rectangular (as during training) to a square (which does not contain informative geometry). Each of the four distinctive features was present and in the same configuration used during training (see Figure 3d). If participants limited their choice to the corner containing the reinforced feature from training, this indicated they were able to encode featural information and use that information in the absence of informative geometry.

Distal-Features condition. To evaluate flexibility in the encoding and use of features, participants searched in the same rectangular room as during training, but the two features in the geometrically correct corners were removed (see Figure 3e). Choices made during this condition showed whether the participants encoded only the feature in the reinforced corner (i.e., as a beacon) or if the location of the reinforced corner had been encoded relative to some or all the features situated in the other corners (i.e., other features being used as landmarks). If participants were only beaconing to the reinforced feature, they would not be able to differentiate between the two now “featureless” corners. However, if the participants had learned about the spatial relationship of the reinforced feature relative to one or both features in the two geometrically incorrect corners, this information would be sufficient to determine the location of the previously reinforced corner.

Cue-Conflict condition. To evaluate how the spatial information provided by features and geometry are weighed relative to each other, participants were provided with a conflict situation. During this condition, participants searched in the same rectangular room as in training, but each feature was repositioned one corner clockwise (see Figure 3f). Thus, if participants weighed the featural information more heavily, it was expected that more choices would be made to the corner with the reinforced feature (although now situated in a geometrically incorrect corner), whereas if the participants weighed the geometric information more heavily more choices would be made to one or both geometrically correct corners (although each now contained incorrect featural cues).

Data Analyses

Out of 120 participants, 16 failed to successfully complete the VRSR training trials and therefore did not complete the testing conditions (6/35 participants from the Under 30 group, 7/40 participants from the 60-69 age group, 3/19 participants from the 70-79 age group, and 0/10 participants from the 80+ age group). As I was mainly interested in the effect of aging on reorientation, participants who failed to complete the VRSR task were not included in further analyses. Assessments and VRSR data from these 104 participants were analyzed. One participant failed to complete the MRT due to experimental error, but this individual’s data were included for all other analyses. Assessment and VRSR data was scored a second time by an independent researcher and inter-rater agreement was 98%.

Due to unequal sample sizes among age categories, and the use of binomial data as the dependent variable in the VRSR task, all analyses were completed using non-parametric statistical procedures.

Assessments. Non-parametric, bivariate correlations were used to determine if there were relationships between accuracy on the MoCA, and the MRT, digit span length on the DST, general information from SSRA and Age group. Linear regression analysis followed the correlation analysis to examine the strength of Age group effects on the assessments. Results from the MoCA, MRT, and DST were not binomial, therefore, ANOVAs were used to determine if Sex affected performance on MoCA, MRT, and DST. All tests were evaluated using the significance level of $p < .05$.

VRSR. All choices made by the participants were recorded, although only the first choices made during the testing trials were used for analyses. In addition, only the first block of testing was analyzed. This was decided to avoid the possibility that the participants might have used their experience with the test trials during the first block to influence their choices during the second block. A Kruskal-Wallis test, a non-parametric alternative to a one-way ANOVA, was used to examine the influence of Age Group on the proportion of choices made to the corners, as well as the influence of Sex on the proportion of choices made to the corners, during each of the five testing conditions. Significant effects were further examined using the Binomial Proportion test, to determine if the proportion of choices to the correct corner(s) was significantly greater than the other corners, and the Wilcoxon Signed Rank test, a non-parametric alternative to a dependant samples t-test, was conducted to determine whether the proportion of choices made to two particular corners differed from each other. All tests were evaluated using the significance level of $p < .05$.

Assessments and VRSR. A Mann-Whitney U test, a non-parametric alternative to an independent t-test, was used to determine if accuracy on the MoCA, and the MRT, and digit span length on the DST differed based on accuracy in the VRSR task. For the Mann-Whitney U test, participants are grouped according to whether their choice was made to a correct or incorrect corner for each testing condition. The total number of participants is then used to determine if these groups significantly differ from one another. A Pearson's chi-squared test was used to determine if there were relationships between ownership of a computer, length of ownership, frequency of computer usage, and accuracy on the VRSR task. All tests were evaluated using the significance level of $p < .05$.

Results

Assessments Results

Age group was negatively correlated with MRT score and video game ownership, and positively correlated with reported computer skill level and reported game skill level (see Tables 1 and 2).

Individuals with higher MoCA scores performed more accurately on the MRT and had longer digit spans on the DST. Accuracy on the MoCA was positively correlated with ownership of a computer, but negatively correlated with frequency of computer usage and reported computer skill level. It should be noted that there were participants, both younger and older, that scored lower than the common cut off score of 26, which is typically interpreted as an indicator for mild cognitive impairment. However, the participants in this study varied in culture, age, and educational background, which creates a situation that makes it difficult to interpret the MoCA scores. For example, the English version of the MoCA test was used, and many of the younger participants were international ESL students who showed difficultly with portions of the test involving language and language-based memory. In addition, the older adults had a varied education background. Thus, the MoCA was not planned to be used as a screening tool, but rather to gather general information about the participants' cognitive abilities.

The MRT score was negatively correlated with frequency of computer usage, reported computer skill level, and reported game skill level. Computer ownership was negatively correlated with frequency of computer usage.

Table 1.

Mean and SD of MoCA, MRT, and DST based on Age group

Age Group	Sex	n	Age		Assessment	Assessment Score	
			Mean	SD		Mean	SD
Under 30	Women	18	20.8	2.3	MoCA	25.8	2.5
					MRT	13.2	9.0
	Men	17	21.7	2.8	DST	5.49	1.2
60-69	Women	26	65.0	2.6	MoCA	26.4	3.2
					MRT	12.2	7.6
	Men	14	65.4	3.4	DST	5.6	1.0
70-79	Women	12	74.1	3.1	MoCA	25.1	2.5
					MRT	12.0	7.5
	Men	7	74.9	2.9	DST	5.3	0.9
80+	Women	5	83.8	1.9	MoCA	24.2	2.5
					MRT	5.8	3.4
	Men	5	84.8	1.6	DST	5.5	1.1

Table 2.

Descriptive statistics and correlation matrix showing relationships between MoCA, MRT, DST, and selected SSRA questions (n = 104)

	Mean	*SD*	Age group	MoCA	MRT	DST	Computer Ownership	Video Game Ownership	Length Computer Ownership	Frequency Computer Usage	Reported Computer Skill Level	Reported Game Skill Level
Age group			1									
MoCA	26.08	2.55	-.125	1								
MRT	12.43	8.08	-.199*	.337**	1							
DST	5.45	1.08	-.026	.252*	.141	1						
Computer Ownership	.94	.24	-.116	.398**	.142	-.011	1					
Video Game Ownership	.41	.50	-.472**	.098	.151	.115	.132	1				
Length Computer Ownership	4.9	.46	.107	.050	.207*	-.031	-.038	-.008	1			
Frequency Computer Usage	1.39	1.06	.160	-.279**	-.212*	-.062	-.577**	-.134	.049	1		
Reported Computer Skill Level	2.20	.76	.296**	-.341**	-.416**	-.006	-.318**	-.184	-.013	.395**	1	
Reported Game Skill Level	3.22	.91	.469**	-.121	-.262**	.026	-.167	-.419**	-.096	.207*	.371**	1

Note. **Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Subsequent regression analyses revealed significant effects of Age group on MRT performance, but not on MoCA or DST performance (see Table 3).

Effects of Sex on performance on the assessments were also examined. ANOVA analyses revealed marginally significant effects of Sex on the MRT, $F(1, 101) = 3.03$, p = .085, whereas there were no significant effects of Sex on the MoCA or DST ($F(1, 101) = .51$, p = .479 and $F(1, 101) = .32$, p = .574, respectively).

Table 3.

Regression analyses standardized ß-values and their corresponding p-values of MoCA, MRT, and DST

Assessment	Standardized β	*p*
MoCA	-.13	.205
MRT	-.199	.043
DST	-.026	.790

VRSR Results

Overall analyses revealed no significant Sex differences in VRSR task performance (see Table 4). Analyses were completed on choices made to the geometrically correct corners during the Geometry-Only and All-Positive conditions, on choices made to during feature corner during the Features-Only condition, on choices made to the correct corner during the Distal-Features condition, and on choices made to the feature corner during the Cue-Conflict condition. As no significant Sex differences were found, Sex was not considered in further analyses.

Table 4.

Kruskal-Wallis H and p value of the effects of sex on the VRSR task conditions

VRSR Condition	H	*p*
Geometry-Only	.196	.658
All-Positive	.002	.968
Features-Only	.936	.333
Distal-Features	.000	.997
Cue-Conflict	.040	.841

Geometry-Only condition. For all analyses of the Geometry-Only condition, the corner that contained the reinforced feature during training was labeled as the *correct* corner, and the corner diagonally opposite to the correct corner was labeled as the *rotational* corner (Note: the correct corner and the rotational corner are both geometrically correct and indistinguishable during this test as the distinctive features were not available). Participants chose the two geometrically correct corners (correct and rotational corners; $M = .80$, $SE = .04$) significantly more than the geometrically incorrect corners ($M = .21$, $SE = .04$; Wilcoxon: $Z = 6.16$, $p < .001$). The proportion of choices made to the two geometrically correct corners was not significantly affected by Age group, (Kruskal-Wallis: $Z = 9.085$, $p = .059$). Despite not finding significant Age group effects, analyses based on *a priori* predictions were completed on each Age group to better understand if there were subtle differences among the groups that would be important for future research. Indeed, participants across all but one Age group chose the geometrically correct corners significantly more than the geometrically incorrect corners; the exception was the 80+ Age group ($M_{Correct} = .60$ vs $M_{Incorrect} = .40$; Wilcoxon: $Z = .632$, $p = .527$), see Table 5). Overall, these results suggest that as a group, participants under the age of 80 were able to use geometry when the distinctive features were removed, but the 80+ Age group were not.

Table 5.

*Mean, SE, Wilcoxon Z, and associated p values. Dependent measure was the proportion of corner choices to the geometrically correct and incorrect corners based on VRSR task condition and Age group. * indicates a significance p <0.05.*

Condition	Age group	Mean		*SE*		Z	*p*
		Correct	Incorrect	Correct	Incorrect		
Geometry-Only	Under 30	.69	.34	.08	.08	2.06	.040*
	60 - 69	.87	.13	.05	.05	4.64	< .001*
	70 - 79	.95	.05	.05	.05	3.90	< .001*
	80 +	.60	.40	.16	.16	.63	.527
All-Positive	Under 30	.86	.14	.06	.06	4.23	< .001*
	60 - 69	.79	.21	.07	.07	3.68	< .001*
	70 - 79	.79	.21	.10	.10	2.52	.012*
	80 +	.70	.30	.15	.15	1.27	.206

All-Positive condition. For all analyses of the All-Positive condition, the corner that contained the positive feature during training was labeled as the *correct* corner, and the corner diagonally opposite to the correct corner was labeled as the *rotational* corner. Participants chose the two geometrically correct corners (correct and rotational corners; *M* = .80, *SE* = .04) significantly more than the geometrically incorrect corners (*M* = .20, *SE* = .04; Wilcoxon: Z = 6.23, *p* < .001). The proportion of choices made to the two geometrically correct corners was not significantly affected by Age group, (Kruskal-Wallis: Z = 1.99, *p* = .737). However, to compare my results during this condition with those of the Geometry-Only condition, analyses based on a priori predictions were completed on each Age group. As with the Geometry-Only condition, as a group, the participants in the Age groups Under 30, 60-69, and 70-79, chose the geometrically correct corners significantly more than the geometrically incorrect corners, whereas as a group the participants in the Age group 80+ once again did not (see Table 5). This result shows that the addition of featural information, albeit uninformative, did not facilitate the encoding of geometry for our oldest group of participants.

Participants in the Age groups under 80 showed no significant difference in geometrically correct choices during the All-Positive condition ($M_{Geometrically\ Correct}$ = .82, *SE* = .04) compared to the Geometry-Only condition ($M_{Geometrically\ Correct}$ = .81, *SE* = .04; Wilcoxon: Z = .17, *p* = .862). Likewise, the 80+ Age group performed similarly in the All-Positive condition (*M* = .60, *SE* = .04) compared to the Geometry-Only condition (*M* = .70, *SE* = .04; Wilcoxon: Z = .58, *p* = .564), suggesting that the addition of the featural information did not facilitate encoding of geometry.

Overall, the results from these two conditions show participants under the age of 80 incidentally encoded geometry during training and could use that information to identify the possible goal location when the features were unavailable or made uninformative. As a group, the participants over the age of 80 were unable to use geometry when features were not available. Together these convergent results suggest that the ability to incidentally encode geometry may decline over the age of 80.

To better understand the decline in geometry use, I further examined the 80+ group at an individual level. As can be seen in Table 6, all but two of the participants made a geometrically correct response during either the Geometry-Only or the All-Positive condition, but only half of the individuals showed consistent geometrically correct responses across both conditions (see Table 6).

Table 6.

Choices to geometrically correct corners by participants in 80+ Age group in the VRSR task

Participant	Geometry-Only condition	All-Positive condition
1	No	Yes
2	Yes	Yes
3	Yes	Yes
4	No	Yes
5	Yes	Yes
6	No	No
7	No	No
8	Yes	No
9	Yes	Yes
10	Yes	Yes

Features-Only condition. For all analyses of the Features-Only condition, the corner which contained the reinforced feature during training was labeled as the *correct* corner. For this condition, the shape of the room was changed from a rectangle to a square, which removed the informative geometry, leaving only the featural information available to reorient. Overall, the proportion of choices to the correct corner (*M* = .93, *SE* = .03) was significantly greater than chance (0.25; Binomial: *p* < .001). This pattern was seen in all Age groups (see Table 7). The proportion of choices to the correct corner did not differ among Age groups, (Kruskal-Wallis: Z = 6.08, *p* = .193). Overall, these results indicate participants in all Age groups could encode and use feature cues, in the absence of informative geometry to successfully reorient.

Table 7.

*Mean, SE, and p value of proportion of corner choices to the correct corner of Features-Only condition of the VRSR task based on Age group. ** indicates a significance p <0.001.*

Age group	Mean	*SE*	*p*
Under 30	.97	.03	< .001**
60 - 69	.85	.06	< .001**
70 - 79	.95	.05	< .001**
80 +	1.00	.00	< .001**

Distal-Features Condition. For all analyses of the Distal-Features condition, the corner which would have contained the reinforced feature during training was labeled as the *correct* corner, and the corner diagonally opposite to the correct corner was labeled as the *rotational* corner. The purpose of the Distal-Features condition was to determine if participants were able to encode and use one or both features in the two geometrically incorrect corners, as landmarks to identify the location of the correct corner. The participants were able to choose the geometrically correct corners (*M* = .78, *SE* = .04) significantly more than the geometrically incorrect corners (*M* = .22, *SE* = .04; Wilcoxon: Z = 5.84, *p* < .001). The proportion of choices to the geometrically correct corners did not differ among Age groups (Kruskal-Wallis: Z = 1.10, *p* = .894). Furthermore, across all Age groups the participants were choosing the correct corner (*M* = .58, *SE* = .05) significantly more than the rotational corner (*M* = .20, *SE* = .04; Wilcoxon: Z = 4.45, *p* < .001). This result supports that regardless of Age group, the participants were using one or both remaining distal features to determine the location of the correct corner. Again, although the results did not reveal significant age effects, based on *a priori* prediction, further analyses were completed, and the results suggest that there is a slight decline in the use of distal featural information in the 70-79 and 80+ Age Groups (see Table 8).

Table 8.

*Mean, SE, Wilcoxon Z, and p value of proportion of corner choices to the correct and rotational corners in the Distal-Features condition of the VRSO task based on Age group. * indicates a significance p <0.05.*

Age group	Mean		*SE*		Z	*p*
	Correct	Rotational	Correct	Rotational		
Under 30	.60	.23	.08	.07	2.41	.016*
60 - 69	.59	.15	.08	.06	3.16	.002*
70 - 79	.53	.21	.12	.10	1.60	.109
80 +	.50	.30	.17	.15	.71	.480

Cue-Conflict Condition. For all analyses of the Cue-Conflict condition, the corner which would have contained the positive feature during training was labeled as the *geometric* corner. The corner, one position clockwise, which now contained the positive feature was labeled as the *feature* corner. For the Cue-Conflict condition, it was hypothesized that participants would weigh featural cues over geometric cues as suggested by previous research (Kelly & Bischof, 2005; Ratliff & Newcombe, 2008b; Sturz & Diemer, 2010). Therefore, in my analyses I examined proportion of choices to the feature corner as my dependant variable. Overall, participants chose the feature corner (M = .92, SE = .03) significantly more than chance (0.25; Binomial: $p < .001$; see Table 9). The proportion of choices to the feature corner did not differ as a function of Age group, (Kruskal-Wallis: Z = 3.09, p = .544). These results suggest regardless of age, adults showed a similar preference for featural cues over geometric cues.

Table 9.

*Mean, SE, and p value of proportion of corner choices to the feature corner in the Cue-Conflict condition of the VRSR task condition based on Age group. ** indicates a significance p <0.001.*

Age group	Mean	*SE*	*p*
Under 30	.91	.05	< .001**
60 - 69	.95	.04	< .001**
70 - 79	.95	.05	< .001**
80 +	.80	.13	< .001**

Assessments and VRSR Results

Analyses using the Mann-Whitney U test was completed to determine if accuracy on the MoCA, MRT, and digit span length on the DST differed based on accuracy in the VRSR task. My results indicate that accuracy on these assessments did not differ based on accuracy in the VRSR task (see Table 10).

Table 10.

*Mean, SE, Mann-Whitney U, and associated p values. Dependent measure was the proportion of corner choices to the correct and incorrect corners based on VRSR task condition and assessment. * indicates a significance p <0.05.*

Condition	Assessment	Mean		*SE*		U	*p*
		Correct	Incorrect	Correct	Incorrect		
Geometry-Only	MoCA	26.30	25.14	.27	.56	722	.073
	MRT	13.05	10.59	.87	1.68	780	.205
	DST	5.50	5.32	.11	.28	807	.233
All-Positive	MoCA	26.18	25.59	.25	.68	875	.532
	MRT	12.70	11.77	.85	1.86	876	.590
	DST	5.40	5.68	.12	.24	835	.330
Features-Only	MoCA	26.04	26.38	.25	1.19	344	.478
	MRT	12.83	8.5	.81	2.02	273	.134
	DST	5.50	4.88	.11	.30	274	.112
Distal-Features	MoCA	26.19	25.63	.27	.56	909	.411
	MRT	12.82	11.35	.91	1.32	914	.633
	DST	5.51	5.29	.12	.24	866	.236
Cue-Conflict	MoCA	25.99	26.89	.25	.86	368	.359
	MRT	12.79	9.00	.81	2.38	294	.211
	DST	5.49	5.11	.11	.31	360	.294

Results from the SSRA, showed that accuracy during the All-Positive condition of the VRSR task significantly differed based on length of computer ownership (χ^2(4, N = 106) = 11.46, p = .022, ϕ = .329). In addition, accuracy during the Features-Only condition significantly differed based on frequency of computer usage (χ^2(4, N = 108) = 11.16, p = .025, ϕ = .321). Other considered computer associated factors from the SSRA, such as computer ownership, did not influence participants' performance during the VRSR task conditions. Although some results were found to be significant, caution should be taken during interpretation as results were inconsistent across VRSR test conditions. The SSRA was used to gather general information regarding participants computer/video game familiarity however, despite modifications being made, the survey did not include questions that enabled researchers to determine if other factors, such as main type of video game played, could have influenced VRSR performance (see Discussion).

Discussion

During this experiment, I examined how adults use geometric and featural information when reorienting in an immersive VR environment and whether age influenced how these cues were used. First, I examined how age affected adults' ability to incidentally encode geometric information when trained with distinctive featural information present, and whether the presence of the featural cue associated with reinforcement during training (although made uninformative during testing) facilitated the encoding of geometry. Second, I examined how age affected adults' ability to encode and use featural information in the absence of informative geometry. Third, I examined whether age affected how participants encoded and used featural information located in the corners distal to their reinforced corner. Fourth, I examined how age affected how participants weigh featural and geometric information when these cues provided conflicting information regarding the goal location. In addition, performance on the MoCA, MRT, DST, and SSRA performance was evaluated; performance during these assessments was used to determine if the cognitive abilities measured by these assessments might be predictive of spatial cue use during reorientation the VRSR task.

Assessments

MoCA, MRT, and DST. As navigation is a complex ability involving numerous cognitive and spatial skills, many tasks have been developed to assess these skills. During the current study I chose the MoCA, MRT, and DST assessments, as they are common tasks used both in aging and orientation research, to examine whether performance on these measures would be predictive of cue use during the reorientation task. The MoCA tests a variety of cognitive abilities, and is most often used to obtain a general measure of cognitive performance (Davis & Weisbeck, 2016; Marquardt, 2011; Moffat, 2009). Previous research has also investigated which specific cognitive abilities correlate with spatial orientation. For instance, accuracy during spatial maze learning tasks can be predicted by measures of visual and verbal memory as tested by the MoCA, as well as mental rotational ability tested as by the MRT (Astur et al., 2004; Moffat et al., 2001; Parsons et al., 2004). The DST, which tests attention and working memory, has also been used when investigating spatial orientation abilities (Guariglia & Nitrini, 2009; Moffat et al., 2001; Parsons et al., 2004). As attention and working memory are shown to decline with aging, the DST is often used to examine age-related cognitive changes (Grégoire & Van der Linden, 1997; Hester et al., 2003; Sun et al., 2005). Therefore, my study aimed to determine if performance during the MoCA, MRT, and DST assessments is predictive of cue use during the VRSR task. Perhaps surprisingly, I found no significant correlations, suggesting that performance on these tasks may not necessarily predict cue use during a reorientation task. The ability to navigate is complicated process, orientation is only one of the many abilities involved. Despite these tasks being shown to be related to spatial navigation, results from this study show that performance on these tasks may not be related to specific abilities involved in orientation, such as cue use. Further research is needed to determine which aspects of orientation are related to performance on these tasks.

SSRA. Although the other assessments revealed no correlations between the VRSR task, additional information gathered through the SSRA suggests that there may be other factors, such as length of computer ownership or frequency of computer use, that may be related to performance on reorientation tasks. This suggests that familiarity with computers may facilitate cue use and adds to previous research that suggests that video game experience affects spatial cognition (Spence & Feng, 2010). Additionally, it was found that Age group showed a positive correlation with reported computer and gaming skill, whereas the MoCA showed negative correlation with reported computer and gaming skill. These findings seem to oppose previous findings and suggests that the influence of computer use and gaming on spatial cognition needs to be further examined. Future research should also include more detailed information regarding computer use and gaming, as different programs used, or games played could cause varying results among participants. For example, in my study the modified SSRA included questions regarding frequency of gaming and reported gaming skill level. However, I did not include specific questions regarding the type of games played. This factor is important to include in future research as the type of game played may affect spatial ability, as well as men and women, differently (Spence & Feng, 2010). In addition, studies examining the effects of video game experience often define ‘expert gamers” as those who played a certain number of hours of a action, first-person shooter style video game (Boot et al., 2008). Experience in first-person shooter style video games shows increased performance in spatial related abilities such as object-tracking, mental rotation, and visual short-term memory (Boot et al., 2008). In my study, it is impossible to differentiate between participants who play first-person shooter style video games versus participants who play other types, such as puzzle or educational style games which are less spatially involved. Thus, the inconsistent SSRA results could be accounted for by the type of video games participants had been exposed to prior to this study.

Use of Featural Cues

The current study shows that adults can encode and use featural information during reorientation, and these feature cues can be used when informative geometry is absent. These results are supported by previous studies of reorientation across a variety of environments (Hermer & Spelke, 1996; Kelly & Bischof, 2005; Sturz et al., 2012; Sutton et al., 2010). Although this is not in itself surprising, as to successfully learn the task the participants would necessarily need to encode featural information, establishing cue independence was an important step in understanding how participants relied on features and geometry for subsequent examination of cue conflict situations.

When learning the goal location, the participants in my study could have, one the one hand, encoded only the properties of the feature directly associated with reward, known as a beaconing strategy. If this was the case, removal of this feature would result in the participants not being able to discriminate between two featureless, geometrically identical corners. On the other hand, the participants may have encoded the properties of the features in the non-reinforced corners and would be able to use these other features if the reinforced feature was removed. Indeed, this was the case. Overall, the results from my study indicate that adults use distal featural cues in a landmark-type way. Although overall, I did not find a main effect of age on the ability to use distal features, a clear decline in performance was seen in 70 – 79 and 80+ Age groups. *A priori* I predicted that age would affect the encoding of distal spatial information, so I further examined this performance decline. Although my results are inconclusive, they provide evidence that the use of distal information may be reduced for older adults compared to younger adults. During the Distal-Features condition in this study, the two feature cues in the geometrically correct corners were removed, leaving two featural cues distal from the target location. It is possible that the participants were selecting the two featureless corners during testing because the reinforced feature cue from training was not present and the two other remaining corners contained distal feature cues that were incorrect. Previous research examining the use of distal featural information have used conditions with only one distal feature cue present, which may allow for a clearer evaluation of whether the participants were using the distant feature, or simply selecting among the featureless corners. Results from my study are still important as they provide a baseline for future research and suggests that the use of distal cues by adults over the age of 70 needs to be closer examined. Follow-up research should include a condition with only one distal feature to better understand the strategies being used and if there is further evidence to support an age-related decline in the use of distal featural information.

Use of Geometric Cues

My study examined whether adults incidentally encode geometric information when trained to find a goal location with distinctive featural cues present, and if so, would this ability show age-related decline. The incidental encoding of geometry was examined in two ways. First, through the removal of all distinctive featural cues such that only the geometric information provided by the shape of the environment was available. Second, through the replacement of all distinctive featural cues with one identical feature – replicas of the positive feature, for each participant, were placed in the four corners. These two approaches allowed me to examine whether participants had encoded the geometric information from the shape of the room during training, and whether the presence of featural cues associated with reinforcement (although not informative) would facilitate the ability to use geometry (Graham et al., 2006; Kelly & Spetch, 2004; Waller & Lippa, 2007). My results showed that although participants had encoded the geometry, this was age-dependent as the 80+ Age group did not show geometric cue use. My results, however, did not support previous research which showed that the presence of a feature associated with reinforcement facilitated the use of geometry. Although, generally the proportion of choices to the geometrically correct corners were greater during the All-Positive condition compared to the Geometry-Only condition, performance did not statistically differ. For many of the Age groups, geometrically guided choices were already quite high, so this may simply be a ceiling effect. However, interestingly, the Age group which may have been most able to benefit from any facilitation effects of features, was the 80+ Age group. Yet, no such facilitation was found.

Overall, the results from the Geometry-Only and All-Positive conditions suggests that the ability to encode geometry may decline with age. Further analyses on the Age groups revealed that the 80+ group in both conditions encoded geometry less than the younger groups, a finding consistent with other research (Picucci, Caffò, & Bosco, 2009). Examining data at the individual level showed that approximately half of the participants did show consistent geometry cue use, whereas the other half did not. This variability may reflect differences in the aging process experienced at the individual level, with some people experiencing less decline than others – often referred to as “high-performing” and “low-performing’ older adults” (Cabeza, Anderson, Locantore, & McIntosh, 2002). Together these results are important as they suggest that some adults over the age of 80 may have difficulty more difficulty encoding geometric information in their environment, compared to others. As geometry has been argued to be the foundation upon which my spatial representation is built (Cheng, 1986), the loss of geometric encoding may be an important factor for understanding the progression of age-related spatial decline.

Weighing of Cues

Previous research in both non-navigable and navigable environments shows that when featural cues are placed in conflict with geometric cues, human participants consistently rely more heavily on featural cues than geometric cues (Kelly & Spetch, 2004; Lourenco et al., 2011; Sturz, Brown, & Kelly, 2009; Sturz & Diemer, 2010). Results from the conflict test during my study showed that adults consistently weigh featural information more heavily than geometric information. One important factor to note is that the results from the Geometry-Only and All-Positive conditions showed that the 80+ Age group did not encode geometric information. Thus, in this cue conflict situation, the 80+ Age group were likely not experiencing a true conflict.

Future Research, Implications, and Conclusions

As mentioned earlier, there is evidence that the two brain hemispheres encode featural and geometric cues differently. Research examining hemispheric lateralization generally shows that left hemisphere attends to featural information, whereas the right hemisphere attends to geometric information (Macneilage, Rogers, & Vallortigara, 2009; Ocklenburg & Güntürkün, 2012). In regard to age-related changes to lateralization, one study suggests that the right hemisphere is more sensitive to the effects of aging than the left hemisphere (Daselaar & Cabeza, 2005; Dolcos, Rice, & Cabeza, 2002). Evidence also supports that there are age-related decreases in functional lateralization (Cabeza, 2002), as older adults show increased hemispheric asymmetry compared to younger adults (Cabeza et al., 2002). Recently a review on the age-related effects on the use of geometric and featural cues shows that declines in orientation ability may be due to decreased ability for older adults to use cues in combination (Caffò et al., 2017). Caffò and colleagues (2017) suggest that geometric information signifcanly supports featural cues, and thus as the ability to encode geometric information declines, so does the abillity to use featural cues in a sufficient manner. Results of my study show support for this theory, as adults over the age of 80 showed deficits in encoding geometry. Furthermore, results from the Distal-Features condition indicates that over the age of 70, adults begin to show deficits in the use of distal featural information, which could be related to the decline in geometric encoding and the inability to use the geometric information in combination with the distal feature cues. Although my study included a variety of spatial-based tasks, there are many others that were not included that could be used to further investigate how the two hemispheres process spatial information. For example, research exploring left-right orientation, examined adults over the age of 75 and their ability to make left-right hand judgments was less accurate than that of younger adults (Saimpont, Pozzo, & Papaxanthis, 2009). It is possible that tasks that measure left-right orientation, or the ability to make left-right discriminations may be related to performance on a reorientation task.

Additionally, future research could examine different types of mental rotation, in particular, mental rotation of object versus mental rotation of body, as previous research has suggested that these abilities require different strategies (Kaltner, Riecke, & Jansen, 2014; Wraga, Shephard, Church, Inati, & Kosslyn, 2005). Additionally, research has suggested that older adults show a decline in performance of mental rotation of body compared to younger adults (Devlin & Wilson, 2010; Jansen & Kaltner, 2014; Kaltner & Jansen, 2016). Therefore, it would be ideal to include tests that measure different types of mental rotation to determine if certain types on mental rotation ability show significant correlations with orientation ability.

Future research examining age-related decline in spatial reorientation should focus on examining individuals 80 years and older to better understand whether, with age, the incidental encoding of geometry does indeed decline within a healthy population. This is necessary information to help create more age-friendly environments, as older adults experience a decrease in the ability to navigate. Accommodations could be made to older adults' environments that include using more salient, featural based cues, allowing for a more independent lifestyle. Results from this study, despite having a limited number of participants, indicate that half the participants were making consistent choices in both the Geometry-Only and All-Positive conditions and that the variability may reflect differences in the aging process. Although particularly difficult to recruit, perhaps a study with a larger sample of adults over 80 might better established how geometric cue use declines with age.

The results from this study indicate that adults can use featural and geometric cues during reorientation in a virtual environment. Examining the effects of age on cue use during reorientation revealed that the ability to use distal featural information decreased after the age of 70 and the ability to encode geometry decreased after the age of 80. These results support previous findings, and additional further my current knowledge about the effects of age on geometric and featural information use during reorientation. This study also provides a baseline for future research examining the effects of aging on the encoding and use of geometric and featural information, as the results indicate that age-related decline in cue use is most evident in adults over the age of 80. The results from this study may be used to as a guide to what types of information older adults should use for more efficient and independent navigation. Moreover, the results provide a starting point for future aging research examining orientation. It is estimated that 60% of older adults living with Alzheimer's disease experience disorientation and become lost in the community during the course of their disease (Rowe & Glover, 2001), and this becomes a growing concern as the population of older adults living with Alzheimer's continues to increase. Results from this study and similar research can therefore provide information to caregivers to create more age- and dementia-friendly environments.

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Appendix A

Verbal Instructions

Thank you for participating in this study.

I will now ask you to fill out a couple questionnaires containing a few general questions. Please answer these questions to the best of your ability. You can choose to respond either in writing or verbally. You can refrain from responding to any of these questions if you so choose. There is no penalty for refusing to respond to a question. Once we have gone through these questions, we will begin the experiment.

I am going to read a few questions. Please respond as accurately as possible. Please ask if you require clarification about any of the following questions.

I am going to show you a few pictures which show line drawn figures. I would like you to indicate which two of the four figures on the right are identical to the figure on the left by circling (or pointing to) the letters underneath the figures. This test is timed, however if you do not know the answer, please do not guess just simply leave it blank and move on to the next question.

I am going to read out a few lists of digits, and I would like you to try to repeat the digits in the order in which I read them out. For example, one of the lists could be, 4, 7, 1.

I will ask you to be seated in the wheelchair, put on the goggles and hold a button. I will then carefully position the wheelchair to a new location within the room. Once we are ready, I will ask you to press the hand-held button to begin experiment. Using your feet to move the wheelchair will allow you to move through the virtual room seen through the goggles. Your goal is to move to each corner within the room to locate a hidden “Good Job” message with as few choices, as possible. If you make an incorrect choice, a message stating “Wrong” will appear and you will be allowed to make another choice. Please know that at first you will need to guess as to where this message might be located in the room, as there is no way of knowing except through trial and error. When you are in a corner that you want to choose, simply press the button in your hand to see if the message appears. Once you find the “Good Job” message I will ask you to remove the goggles and I will wheel your chair back to the starting position. We will do this several times. It is important to know that at first, I will let you choose as many corners as you need to find the “Good Job” message, but after a few times I will limit the number of choices you can make. It is also important to know that the “Good Job” message will not be present on every trial – but I still would like you to try and pick the corner you think most likely contains the “Good Job” message.

Do you have any questions about these procedures? To summarize, when you are viewing the virtual room, you need to pick the corner that you think contains the “Good Job” message. Clicking the hand-held button will reveal whether the corner has this message or not – try to make your choices as quickly but as accurately as possible.

Appendix B

UNIVERSITY OF MANITOBA

Information and Consent Form

Research Project Title: Age and Spatial Reorientation

Principal Investigator: Megan Siemens, 2nd year Master's Student, Psychology, Phone: (204) ***-****, Email: siemen17@myumanitoba.ca

Research Supervisor: Dr. Debbie Kelly, Professor, Psychology, Phone: (204) ***-****, Email: debbie.kelly@umanitoba.ca

This consent form, a copy of which will be provided to you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about anything mentioned here, or information not included here, you should feel free to ask at any time. Please take the time to read this carefully to understand the purpose of the experiment.

Purpose and Procedures: The purpose of this study is to examine how people regain a sense of orientation when they are lost. During this study, you will be asked to answer a number of questions pertaining to your general health, computer use and navigational abilities. You will be required to give either a verbal or written response. You will be asked to wear a pair of goggles that display a virtual reality room – similar to a three-dimensional movie. As you view the room, you will be seated in a standard wheelchair. This wheelchair will allow you to move around within the virtual room. As you move through the room, you will be asked to make decisions based on what you see. You will make responses by pressing a button held in your hand. At first you may need to use a trial-and-error strategy to figure out what response to make. We estimate that it should take 90 minutes to complete the study. You will receive 2 course credits for participation. However, you may choose to stop the study at any time without penalty.

Potential Risks and Benefits: One known risk that could be associated with this study is experiencing motion sickness or vertigo. To compensate for this risk, you are seated in a wheelchair and your movements in the chair are linked to movements within the virtual environment. The use of the wheelchair has been previously shown to reduce feelings of motion sickness and vertigo. You will also be instructed to remove the goggles in between each trial to help reduce the chances of motion sickness and vertigo. In addition, after completion of the virtual reality spatial task, you will be monitored for approximately 30 minutes to ensure you are not feeling any motion sickness or vertigo and that you are feeling well to leave the University. Although this experiment is not designed to help you personally, the information gathered by this project will contribute to our understanding of how people use information to orient.

Participation in this study will also help you to gain an understanding of how research is conducted.

Storage of Data and Confidentiality: Consent forms will be stored separately from the responses that you have made during the experiment. All consent forms and data will be stored securely by Dr. Debbie Kelly at the University of Manitoba. The data, consent forms and questionnaires will be kept for seven years after the publication of the study, after which it will be destroyed beyond recognition. Findings from this study will be shared at presentations, conferences and in journal articles. However, the data will be reported in a manner where it is not possible to identify individual participants.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being conducted in a safe and proper way.

This research has been approved by Kelley Main, Chair of the Psychology/Sociology Research Ethics Board (PSREB). If you have any concerns or complaints about this project, you may contact any of the above-named persons or the Human Ethics Coordinator at 204-474-7122 or humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Participant’s Signature ________________________________ Date _________________________

Researcher’s Signature ________________________________ Date _________________________

Appendix C

UNIVERSITY OF MANITOBA

Information and Consent Form

Research Project Title: Age and Spatial Reorientation

Principal Investigator: Megan Siemens, 2nd year Master's Student, Psychology, Phone: *University of Manitoba number*: (204) ***-****, *cell* (204) ***-****, Email: siemen17@myumanitoba.ca

Research Supervisor: Dr. Debbie Kelly, Professor, Psychology, Phone: (204) ***-****, Email: debbie.kelly@umanitoba.ca

This consent form, a copy of which will be provided to you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about anything mentioned here, or information not included here, you should feel free to ask at any time. Please take the time to read this carefully to understand the purpose of the experiment.

Purpose and Procedures: The purpose of this study is to examine how people regain a sense of orientation when they are lost. During this study, you will be asked to answer a number of questions pertaining to your general health, computer use and navigational abilities. You will be required to give either a verbal or written response. You will be asked to wear a pair of goggles that display a virtual reality room – similar to a three-dimensional movie. As you view the room, you will be seated in a standard wheelchair. This wheelchair will allow you to move around within the virtual room. As you move through the room, you will be asked to make decisions based on what you see. You will make responses by pressing a button held in your hand. At first you may need to use a trial-and-error strategy to figure out what response to make. We estimate that it should take 90 minutes to complete the study. You will receive $15 (Cdn) for participation. However, you may choose to stop the study at any time without penalty.

Potential Risks and Benefits: One known risk that could be associated with this study is experiencing motion sickness or vertigo. To compensate for this risk, you are seated in a wheelchair and your movements in the chair are linked to movements within the virtual environment. The use of the wheelchair has been previously shown to reduce feelings of motion sickness and vertigo. You will also be instructed to remove the goggles in between each trial to help reduce the chances of motion sickness and vertigo. In addition, after completion of the virtual reality spatial task, you will be monitored for approximately 30 minutes to ensure you are not feeling any motion sickness or vertigo and that you are feeling well to leave the University. Although this experiment is not designed to help you personally, the information gathered by this project will contribute to our understanding of how people use information to orient. Participation in this study will also help you to gain an understanding of how research is conducted.

Storage of Data and Confidentiality: Consent forms will be stored separately from the responses that you have made during the experiment. All consent forms and data will be stored securely by Dr. Debbie Kelly at the University of Manitoba. The data, consent forms and questionnaires will be kept for seven years after the publication of the study, after which it will be destroyed beyond recognition. Findings from this study will be shared at presentations, conferences and in journal articles. However, the data will be reported in a manner where it is not possible to identify individual participants.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

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This research has been approved by Kelley Main, Chair of the Psychology/Sociology Research Ethics Board (PSREB). If you have any concerns or complaints about this project, you may contact any of the above-named persons or the Human Ethics Coordinator at 204-474-7122 or humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Participant’s Signature ______________________________ Date ________________________

Researcher’s Signature ______________________________ Date ________________________