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Age and dementia related differences in spatial navigation within an immersive virtual environment

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A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background: Immersive virtual reality (VR) is an innovative tool that can allow study of human spatial navigation in a realistic but controlled environment. The purpose of this study was to examine age- and Alzheimer's disease-related differences in route learning and memory using VR.

Material/Methods: The spatial memory task took place in a VR environment set up on a Computer Workstation. Participants were immersed by putting video unit goggles over their eyes using a Head Mounted. Participants were shown a path within a virtual city, and then had to navigate it as quickly and accurately as possible. They were granted four learning trials on this path. An interference path was then presented before asking participants to re-navigate the first route at short and long delays. Finally, participants were tested for recognition of the city's buildings and objects.

Results: Young adults were consistently quicker and more accurate in their path navigation than older participants whilst those patients with Alzheimer's Disease made more mistakes on the recognition task in particular, being more likely to mistakenly affirm having seen an element in the city when it was in fact a foil.

Conclusions: Our study would suggest that spatial navigation is susceptible to the effects of aging and Alzheimer's Disease. The potential applications of VR to the study of spatial navigation is seemingly important in that it may help place the science of neuropsychology on firmer scientific grounds in terms of its validity to real world function and dysfunction.

key words: spatial navigation • virtual reality • aging • Alzheimer's disease • ecological validity

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Background

Neuropsychology has proceeded as a science by reducing complex behaviours into component cognitive domains. Domains of cognitive functioning identified by neuropsychologists are numerous. One example of these domains is spatial orientation, which can be defined as the ability to relate position, direction or movements of objects in space [1]. Numerous neuropsychological table-top assessment tools, such as the Topographical Localization Test [1], the Test of Geographic Orientation [2], the Fargo Map Test [3], and the Extrapersonal Orientation Test [4], have been developed to evaluate route learning or topographical memory, a subcomponent of spatial orientation.

The aforementioned pencil and paper tests obviously lack an important aspect of real-world navigation, namely translocation, or at least the illusion of movement, of the body in space [5]. The lack of locomotion excludes the contribution of important sensorimotor, vestibular and proprioceptive information to spatial learning [6–8]. Another crucial difference between psychometric measures and everyday tasks is that the former tests focus on participants' ability to learn and remember routes or locations using a bird's eye view of the world. This type of allocentric knowledge is usually referred to as survey or, configural knowledge [9,10]. Survey knowledge is acquired through multiple navigations of an environment using various routes. In the case of most neuropsychological tests, survey knowledge is attained through secondary means, using maps or pictures, as opposed to a primary navigational experience [11].

In short, it seems reasonable to assume that different processes underlie allocentric and egocentric navigational skills [12–14]. Table-top tests do not provide an adequate evaluation of memory for routes. Furthermore, real-world navigation takes place in a large-scale space, where the environment can not be fully seen or processed from one viewpoint, and must be examined through multiple viewings of its different sections [12,15,16]. Table-top neuropsychological test measures are inherently limited by way of this need for large-scale navigation. Thus, it is difficult to extrapolate impairment from table top test measures to real world dysfunction.

Ecological validity and spatial navigation

In the last few decades, there has been a growing interest in assessing cognitive functioning in more ecologically valid settings [17,18]. Ecological validity is defined as the degree of relevance or similarity a test has to the real world [19]. The concept of ecological validity, as currently used, implies that "the assessment procedure is similar to some aspects of free behaviour in the open environment and that the results of the assessment procedures can somehow predict free behaviour in the open environment" [20]. As noted, traditional neuropsychological tests for memory of routes have limited generalizability to real-world functioning. As such, it is difficult to articulate how performance on a traditional table top neuropsychological test measure relates to everyday performance in a complex functional environment [21]. Efforts to this end however, have been made by a few groups conducting research on navigational learning and memory [e.g., 22–27]. Indeed, various research groups have utilized immersive virtual reality (VR) to increase ecological validity in the study of human spatial navigation. The term virtual environment (VE) is defined as a "three-dimensional data set describing an environment based on real-world or abstract objects and data" [28]. Virtual reality is an ideal platform for human spatial navigation since it allows participants to perceive as well as act upon an interactive environment that can be made very life-like [29]. Participants can be fully immersed in this artificial environment, something that is impossible to do with table-top tests [30], which also allows the experimenter control of the stimuli, which moreover, allows for reproducibility of studies, whilst being able to easily manipulate parameters of the environment [29].

Accordingly, we set out to create a spatial task within a virtual city that we modelled after the California Verbal Learning Test (CVLT; [31]). The CVLT, a widely-used neuropsychological test, assesses learning of verbal material as well as the amount of material retained at various intervals [1]. It has been shown to be the most sensitive measure to AD in a meta-analysis of neuropsychological test findings in this patient population [32]. Our own task aimed at measuring spatial learning and memory over many trials and delay periods. More specifically, participants were asked to navigate a given path over four learning trials after which they were submitted to an interference trial to document proactive interference. This was followed by a short delay recall of the first path, and 20 minutes later, another recall trial for this same path. Time to completion and distance traveled as well as errors in interference (wrong turns) or inaccuracy (bumping into buildings/objects or falling off the sidewalk) were tabulated for each of these trials. Finally, participants underwent a recognition task where they were shown a series of objects and buildings and asked to indicate for each one if they thought it was present or absent from the city.

In keeping with our measure, we set out to answer the following research questions:

1. Do young adults perform better than healthy older adults in terms of speed and accuracy when navigating? Is there also a difference between healthy older adults and patients suffering from AD?
2. Are there qualitative differences in the ability to navigate (e.g., accuracy and precision) between older and young adults?
3. Are there age- or dementia-related differences in the recognition of landmarks following the spatial navigation of a VR environment?

Material and Methods

Participants

We recruited 8 young adults and 7 older adults through the introductory psychology research pool at the University of Toronto at Scarborough. Older participants were screened for psychiatric or neurological disorder as well as for history of moderate to severe head injury, substance abuse or cerebrovascular disease (e.g., stroke) through the administration of a questionnaire and various neuropsychological tests. Two patients with a clinical diagnosis of probable Alzheimer's disease (PrAD) as defined by NINCDS-ADRA [33] were also included in the study. Both patients were un-

Table 1. Demographic characteristics of the population studied.

Test variables	Young (4 men, 4 women)				Old (5 men, 2 women)				P value
	Mean	(SD)	Min–Max	N	Mean	(SD)	Min–Max	N	
Age	25.25	3.33	20–30	8	61.57	10.20	52–83	7	0.00
Education	17.63	2.33	14–20	8	14.71	3.77	9–19	7	0.09
Number of years of computer use	11.25	4.80	5–20	8	10.71	7.87	0–20	7	0.89
Number of years of videogame experience	6.50	5.86	0–15	8	0.14	0.38	0–1	7	0.02

SD – Standard deviation; Min–Max – range of data; N – number of participants.

Figure 1. Layout of the equipment used to conduct this virtual reality experiment (see text for explanation of functionality of each component). 1. ZX-10 Intergraph Computer Workstation. 2. Proview XL-50 Head Mounted Display. 3. miniBird 800 6 Degree-of-Freedom tracker. 4. Joystick. 5. Sony Scan Converter. 6. Mitsubishi Video Cassette Recorder. 7. Sony TV monitor. 8. Movable desk unit.

der the care of a neurologist from Sunnybrook and Women's College Health Sciences Centre (SWCHSC).

The demographic characteristics of the young and older groups are outlined in Table 1. All our participants, except for two men in the younger group, were right-handed. Older and younger adults did not differ significantly in years of schooling (p=0.09). We wanted to establish previous use of computers and videogames by participants because we felt that prior experience might influence performance. The number of hours estimated by research participants is approximate. As can be seen in Table 1, previous exposure to computers is not significantly different between both groups (p=0.88), but it does seem that younger subjects have more experience playing videogames (p=0.02).

The two patients suffering from PrAD were both men. Patient J.H. was 73 years old, and possessed 17 years of education. He had been suffering from PrAD for approximately 5 years. Patient S.D. was 68 years of age and has been suffering from PrAD for 4 years. He had 21 years of education. Both patients had no experience with videogames but had used computers in the workplace.

Equipment

The spatial memory task took place in a VR environment set up on a ZX-10 Intergraph Computer Workstation (Figure 1, element 1). Participants were immersed by putting video unit goggles over their eyes using the Proview XL-50 Head Mounted Display (HMD) designed by Kaiser Electro-Optics Inc. (Figure 1, element 2). This HMD offered a true 1024 X 768 resolution as well as an outstanding colour performance, which sets it apart from other HMDs currently available. The field of view obtained was of 50° diagonally, 30° vertically, and 40° horizontally. The signals received in the HMD video were transmitted through a controller box, which was linked up to the computer workstation. This controller box allowed sending a slightly different image to each screen of the HMD. This allowed us to create an illusion of depth. This stereoscopic vision feature of this VR equipment greatly contributed to the realism of the simulation.

Another feature contributing to the realism of the simulation was the real-time 6-dimensional head motion tracking. The tracking allowed for the display seen in the HMD to move along with head movements, thereby increasing realism and minimizing discrepancies between bodily movement and its expected effect on the environment. Minimizing differences between expected and actual motion was crucial in reducing likelihood of motion sickness in a virtual environment (also called cybersickness). The computer workstation was connected to a miniBird 800 6 Degree-of-Freedom (DOF) tracker from Ascension Technologies which measured position and orientation in space (Figure 1, element 3). To specifically track head motion, we placed a miniBird receiver antenna on top of the HMD. A miniBird transmitter box, which was connected to the 6DOF tracker box, sent magnetic impulses towards the receiver. The receiver measured not only this sent magnetic field pulse but also the earth's magnetic field. It sent all the information back to the tracker box where it was converted to position and orientation values. The miniBird 800 provided measurements accurate to 0.1° for rotations or 0.5 mm for translations.

All of these components were linked to a ZX-10 Intergraph Computer Workstation (Figure 1, element 1). This computer was designed to build and run complex 3D simulations with minimal performance loss. It easily integrated the entire VR peripheral device aforementioned all the while running the VR simulation in real time. The VR practice and test sim-

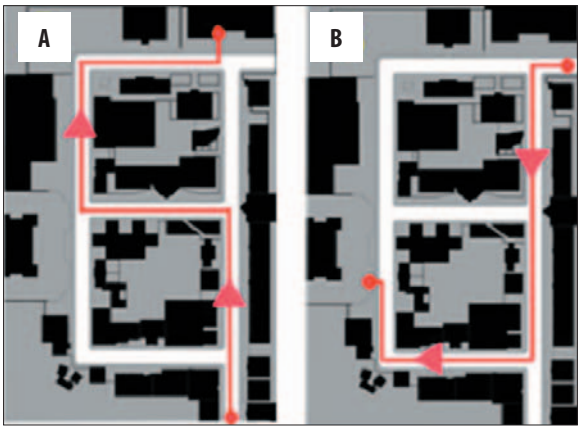

Figure 2. Aerial view of Sunnybrook City, which was composed of 5 streets laid out in the shape of a figure "8". Participants only experienced the city from an egocentric perspective so they were never showed this map. (**A**) Outline of path A. Participants were asked to passively watch, through their HMD, the path being navigated and then retrace this exact path for 4 consecutive learning trials. After a short and a longer time interval, they had to renavigate this path only from memory. (**B**) Outline of path B. Participants were allowed only one trial to learn this path. The learning trial for path B occurred after the fourth learning trial for path A, and just before the short-delay recall for that same path.

Figure 3. Four different views of the city as seen by participants. Buildings were textured using the software 3D Studio Max.

ulations were built on a WorldUp Release 5 platform. The WorldUp software suite was a complete environment to develop and execute flexible 3D simulations. The practice environment consisted of one building, and hilly terrain. It was designed to help participants familiarize themselves with the experience of virtual environments. The test environment was "Sunnybrook City", which was composed of 5 streets laid out in the shape of a figure "8" (Figure 2). The city was realistic in its rendering since buildings were textured using 3D Studio Max to a degree where they could be identified as distinctive landmarks such as a grocery store, a movie theatre or a bank (Figure 3 for sample views). The streets of the city also included sidewalks, standard road signs, and even bus stops. Participants could navigate forward through both of these virtual environments using a joystick (Figure 1, element 4) connected to the miniBird 6DOF tracker which, in turn, modified the scenery seen in the goggles as the participants moved through the city. As previously noted, left and right turns were controlled by head movements.

Our equipment platform also included a Sony Scan Converter (Figure 1, element 5), a Mitsubishi Video Cassette Recorder (Figure 1, element 6) and a Sony TV monitor (Figure 1, element 7). These three elements allowed us to record testing sessions on videotape and carefully score participants' performance at a later time. Finally, the whole platform was mounted on a self-contained rolling unit (Figure 1, element 8) to allow mobility of our equipment.

We tested the equipment prior to the formal study. That allowed us to identify necessary modifications to the setting. The weight of the HMD was only 35 ounces but it did prove to be tiring when it was worn for an extended period of time. Thus, to offset the pressure caused by the weight, we hung the centre of the HMD from the ceiling. To accomplish that, we designed a system of two loops made of nylon strap. One loop was fixed to the middle bar of the HMD, and the second loop, which could be adjusted depending on the participant's height, was linked to it. This second loop was connected to the ceiling by an extensible cord with hooks on both ends.

Another important element needed to keep the equipment stable during testing was to sit participants in a chair that would swivel but wouldn't roll on the floor. To ensure that was possible, the chair was solidly taped to the floor.

Procedures

Participants were first asked to read over an information sheet as well as sign a consent form that were approved by the SWCHSC ethics committee. Subjects were then seated in the immobilized chair, and the HMD was fitted on their head. They were then asked to practice using the joystick and the HMD by travelling through a control VE. This practice period lasted, on average, 5 to 10 minutes depending on the length of time it took participants to flawlessly approach a given building in the control environment.

They were then introduced to "Sunnybrook City". The task they had to accomplish was designed to be a spatial equivalent of the CVLT. The CVLT is a measure of verbal episodic memory that requires participants to learn and recall lists of words. In the current study, subjects first had to learn a given route, which we called path A, over 4 trials (Figure 2A). For each of the 4 trials, participants looked at the screens inside the HMD where they were shown the path they had to learn. This automatized path had been recorded by the computer, and was thus exactly the same across trials and participants. Subjects were then instructed to navigate path A as they would do in real life, which included walking on the sidewalks, and crossing the street at intersections.

Time to completion, distance travelled, as well as navigation errors in the form of wrong turns were tabulated for each trial. In addition, the accuracy in navigation was calculated by counting the number of times people bumped into buildings or wandered off the sidewalk.

After the 4 learning trials, a second route, path B, was presented to subjects. This latter route was made as independent (i.e.

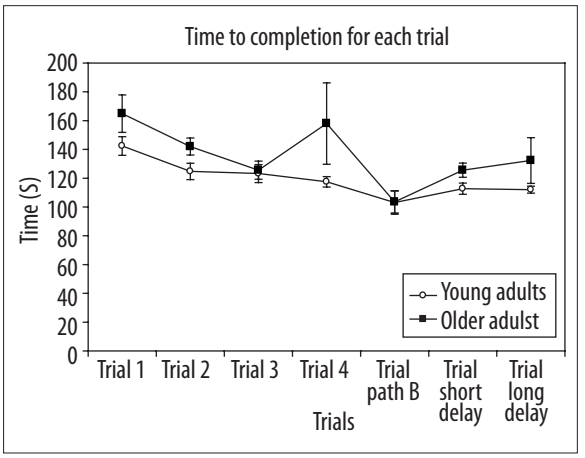

Figure 4. Average time that it took participants to complete each trial. Older adults were slower, on average, to navigate the city.

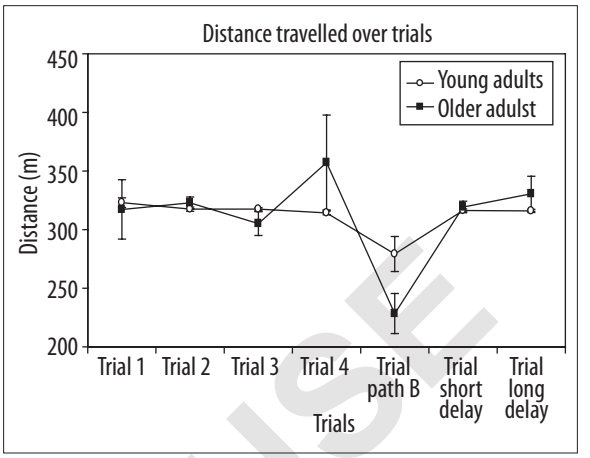

Figure 5. Average distance travelled for each trial. This variable did not produce consistent results across trials.

as little overlap) as possible from path A (Figure 2B). The participants were allowed only one learning trial for path B.

After the learning trial with path B, participants were asked to recall and renavigate path A without any demonstration. Their success was assessed on the same criteria as the ones used during learning trials. After a 20-minute delay, subjects were again asked to recall path A. Following delayed recall, recognition of buildings and objects that were along path A & path B was assessed outside of the VE. Thirty slides of various city elements (buildings, cars, signs) were shown to participants on a computer screen. Nineteen slides contained elements that were effectively located along paths A and B, and 11 foils were objects that participants had not seen. Participants were asked to indicate if they had thought the specific objects shown were present in Sunnybrook City. This task allowed us to evaluate recognition memory for various elements of the city.

During the 20-minute delay, subjects were asked to fill out a cybersickness questionnaire (Boulos & Zakzanis, unpublished; see Appendix A). This questionnaire surveyed the effects and after-effects of being in a VE. During that delay, we also collected demographic information. After the long-delay recall and the recognition trials were completed, we administered a small number of standardized neuropsychological tests to characterize the cognitive status of our older subjects only. This battery included the Mattis Dementia Rating Scale (DRS; [34,35]). This test is typically used to stage dementia severity as it provides an index of cognitive functioning in several domains. We also included the Controlled Oral Word Association Test (COWAT; [36,37]), the Boston Naming Test (BNT; [38]), the Rey-Osterrieth Complex Figure (ROCF; [39]), and the CVLT [31]. The testing session lasted approximately two and a half hours. The two patients suffering from PrAD were administered these tests by a trained psychometrist at their yearly neuropsychological assessment.

Results

Statistical analysis

Five behavioural measures of path learning and memory were obtained. These measures were analysed using Cohen's *d* statistic. This type of analysis allows one to observe the magnitude of difference between groups rather than reducing statistical analysis to mere chance probability, which is the basis of null hypothesis significance testing [40]. Since this study is a prelude to developing a spatial memory test in patients, it is most appropriate to examine which variables are likely to yield differences that may be clinically relevant rather than merely focus on whether or not they meet significance. Cohen [41] established a frame of reference to interpret the magnitude of these differences by stating that an effect size of 0.2 should be considered small, 0.5 medium, and 0.8 large. It is important, however, to acknowledge that the magnitude, and hence, scientific importance of an effect size, should always be interpreted within the experimental context [40].

Performance of young and healthy older participants

The first variable examined was amount of time taken by participants to complete each trial. Healthy older adults took more time on average to navigate path A (Figure 4). Young participants' performance plateaued by the second trial whereas older adults needed 3 trials to complete navigation in less than 130 seconds. Very few mistakes could be made if one were to complete the task in 130 seconds or less. The average time to completion for trial 4 in older adults was artificially inflated by the performance of one participant who became disoriented towards the end of the trial and took 325 seconds (>2 S.D. away) to complete navigation. If we exclude this outlier, older participants completed the fourth trial at an average of 130.16 seconds. Such an average would be more consistent with the improvement shown throughout the first three learning trials.

Younger adults also outperformed older adults when re-navigating path A from memory after a short delay and a longer, 20-minute interval (see Figure 4). The effect sizes for both of these trials were comparable to the differences observed during the first two learning trials. It is interesting to note that the group of older participants showed great variability in performance on the long delay trial as evidenced by a large standard deviation on that trial.

Surprisingly enough, the two groups of participants completed path B in a comparable amount of time. It is important to note that path B contained the same number of turns as

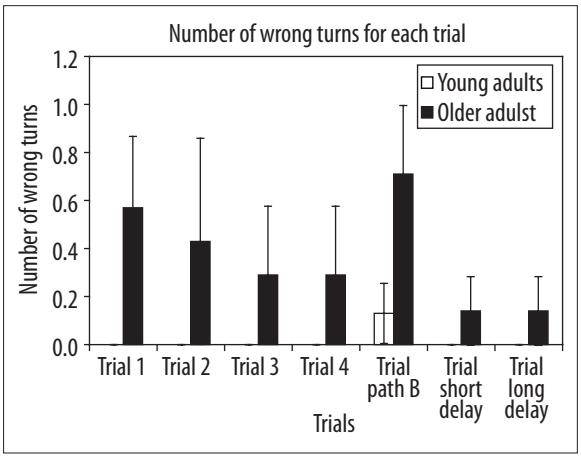

Figure 6. Average number of wrong turns across trials. Older adults made consistently more wrong turns than young participants, demonstrating increased intrusion of incorrect spatial information.

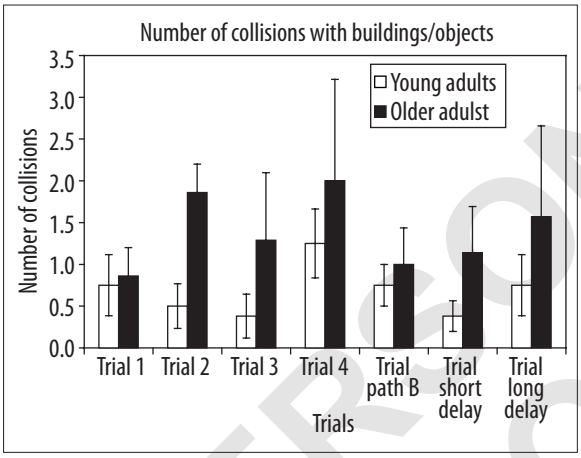

Figure 7. Average numbers of collisions against buildings and objects. This variable did not seem to indicate any significant age-related difference.

path A but was slightly shorter in terms of distance. Hence, this could be completed in a shorter amount of time than path A. The result on this trial might be explained by the fact that this shorter trial did not leave enough room for variability. Furthermore, age-related differences may not be present between navigation of path B compared to the first trial of path A. Older adults' performance on path B might have been improved by the familiarity with the environment. Conversely, this performance might also indicate that young participants' performance was more affected by proactive interference and rendered equal to that of older adults.

The distance travelled did not produce consistent results (Figure 5). Younger participants travelled, on average, a shorter distance than older adults on trials 2 and 4 as well as during short and long delay recall trials. The inverse pattern of results was observed on the remaining trials. It was surprising, however, to find a significant difference for navigation for path B (t=–2.25, p=0.04) indicating older participants' greater efficiency. This lower average of distance travelled for older subjects, yielding a large effect size (d=1.17),

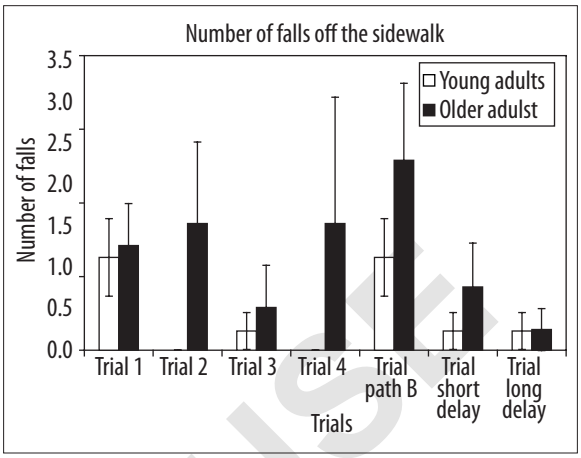

Figure 8. Average number of times participants fell off the sidewalk across trials. Participants were asked to stay on the sidewalk throughout their navigation in order to make their navigation more life-like. We did not find a significant difference in performance between both groups.

was actually due to four older participants getting lost. They were scanning the environment for a long time without moving, just trying to decide where to go. Ultimately, these four participants were not able to reach the final destination, and asked to discontinue the trial.

The number of wrong turns seemed to differentiate the two groups. Older adults made consistently more wrong turns than young participants, demonstrating increased intrusion of incorrect spatial information (Figure 6). Younger adults seem to complete the navigation flawlessly whereas, on average, older adults committed one wrong turn. This difference was most striking on the first learning trial for both paths A and B (Path A, d=1.07; Path B, d=1.01). This variable seemed to yield the most consistent differences throughout trials.

The final two behavioural measures taken across learning and retention trials, collisions with objects or buildings and falls off the sidewalk, reflected the accuracy in the participants' navigation. Results (Figures 7,8) indicated a tendency for younger subjects to be more accurate in their navigation but effect sizes were fairly small. These two variable were, thus, not very useful in differentiating between the groups.

After the long-delay recall trial was completed, a recognition task was administered (Table 2). The performance of both groups on accurately pinpointing items seen in the city was not significantly different (t=0.09, p=0.93; d=0.04). A difference in the number of false positive errors committed yielded, however, a large effect size (d=1.27). Older participants were more likely to mistakenly affirm having seen an element that was in fact a foil. Indeed, no young participant committed any error of this type whereas older adults had an average of 1.71 errors of a "false positive" type. Thus, errors of this nature clearly set both groups apart.

Performance of two patients suffering from mild probable Alzheimer's disease

Another interesting aspect of this study were the preliminary results obtained in two patients suffering from PrAD.

Table 2. Number of total correctly identified items and breakdown by type of errors during the recognition task.

	Young				Old				Cohen's d	OL%
	Mean	(SD)	Min–Max	N	Mean	(SD)	Min–Max	N		
Total score	23.13	2.80	17–26	8	21.29	1.80	19–24	7	0.77	53.94
False positives	0.00	0.00	0	8	1.71	1.98	0–5	7	1.27	35.50
False negatives	6.88	2.80	4–13	8	7.00	2.71	3–10	7	0.04	96.65

SD – Standard deviation; Min-Max – range of data; N – number of participants; Cohen's $d=|M_1-M_2|/SD$ pooled, where M_1 and M_2 are the group means for young and old subjects, respectively; OL% corresponds to the percentage of overlap in the two groups' performance.

Table 3. Performance of the 2 patients suffering from PrAD.

	Time	SD from nean	Distance travelled	SD from mean	Wrong turns	SD from mean	Number of collisions	SD from mean	Fall off the sidewalk	SD from mean
Patient J.H.										
Trial 1	115	>1SD	213	>1SD	1	Within 1SD	4	>3SD	0	Within 1SD
Trial 2	144	Within 1SD	330	Within 1SD	0	Within 1SD	3	>1SD	2	Within 1SD
Trial 3	146	>1SD	330	Within 1SD	0	Within 1SD	4	>1SD	1	Within 1SD
Trial 4	159	Within 1SD	323	Within 1SD	0	Within 1SD	2	Within 1SD	1	Within 1SD
Trial B	132	>1SD	210	Within 1SD	1	Within 1SD	3	>1SD	1	Within 1SD
Short delay	142	>1SD	321	Within 1SD	0	Within 1SD	1	Within 1SD	0	Within 1SD
Long delay	152	Within 1SD	322	Within 1SD	0	Within 1SD	0	Within 1SD	0	Within 1SD
Patient S.D.										
Trial 1	251	>2SD	334	Within 1SD	1	Within 1SD	0	Within 1SD	0	Within 1SD
Trial 2	240	>3SD	381	>3SD	1	Within 1SD	3	>1SD	0	Within 1SD
Trial 3	266	>3SD	443	>3SD	1	Within 1SD	2	Within 1SD	0	Within 1SD
Trial 4	181	Within 1SD	322	Within 1SD	0	Within 1SD	1	Within 1SD	0	Within 1SD
Trial B	111	Within 1SD	197	Within 1SD	3	>3SD	1	Within 1SD	1	Within 1SD
Short delay	160	>2SD	319	Within 1SD	0	Within 1SD	0	Within 1SD	1	Within 1SD
Long delay	158	Within 1SD	298	Within 1SD	0	Within 1SD	1	Within 1SD	0	Within 1SD

SD – Standard deviation.

Patient J.H.'s most striking deficits were on naming tasks. His performance on the BNT was 14 out of 30, which places him below the tenth percentile of his age and schooling are considered. He was clearly shown to be anomic on the Western Aphasia Battery (WAB). He also demonstrated learning difficulties on the CVLT where he was only able to retain four words on the fifth learning trial. The patient's performance on non-verbal tasks was slightly impaired but clearly superior to his verbal skills. He did not copy the ROCF perfectly (31/36) but this performance is within normal range for his age and schooling. This patient also performed well on Judgement of Line Orientation task (30/30) and scored above the 95th percentile on Raven Progressive Matrices.

Performance of J.H. in Sunnybrook City is outlined in table 9. This man performed within average or a little beyond the first standard deviation compared to healthy older participants on almost all measures. The only exceptions to that rule were observed on a few trials when he bumped into buildings or objects more than would be expected from healthy adults. Thus, he demonstrated fairly preserved spatial learning and memory despite severe naming impairment.

Unlike the previous participant, patient S.D. did not show pronounced deficits in naming as his score on the BNT was 29/30, and he was classified as having normal speech on the WAB. His performance on the CVLT, however, was clearly impaired. Even though he was able to learn 7 items by the fifth learning trial, he only remembered 1 item on free recall after a short delay. His performance at copying the ROCF was perfect but he did show slight deficits at non-

Table 4. Scoring cybersickness effects during and after testing

Moment of assessment	Young				Old				Cohen's d	OL%
	Mean	(SD)	Min–Max	N	Mean	(SD)	Min–Max	N		
During test	30.87	8.29	19–45	8	35.57	15.04	20–55	7	0.40	72.89
After effects	12.25	5.90	7–22	8	11.71	4.68	7–19	7	0.09	93.40

SD – Standard deviation; Min–Max – range of data; N – number of participants; Cohen's d=$|M_1-M_2|$/SD pooled, where M_1 and M_2 are the group means for young and old subjects, respectively; OL% corresponds to the percentage of overlap in the two groups' performance.

verbal tasks such as the Raven Progressive Matrices (28/36, 75–90 percentile).

These slight non-verbal as well as memory deficits experienced by S.D. became quite apparent in his performance on spatial learning and memory inside Sunnybrook City (Table 3). The time it took him to complete many learning trials as well as the distance he needed to travel to reach his goal were more than 2 or 3 standard deviations away from the average performance in healthy older adults. This deficit was particularly apparent on the first 3 learning trials as well as the short-delay recall. Overall, S.D. experienced more difficulty than J.H. on all variables except on the collision variable.

Both participants' performance on the recognition task was fairly consistent with what was observed in healthy older adults. J.H. scored 19/30 which is a bit more than one standard deviation away from the mean. He made 3 false positive errors, a performance within one standard deviation of the mean. S.D. answered correctly on 20 out of 30 slides, and only one of his mistakes was a false positive error. Thus, although results on the recognition task were influenced by age (young v/s old), they did not seem to be further degraded in patients suffering from mild PrAD.

Cybersickness

Finally, we examined the results of a cybersickness questionnaire (Boulos & Zakzanis, unpublished), which was administered during the 20-minute delay between the short-delay and long-delay recall trials (Table 4). Results presented here only examined the young and healthy older groups. Participants were asked to rate the intensity of various cybersickness symptoms as felt while in the VE as well as after-effects experienced after coming out of the VE. Possible scores for each subtest ranged respectively from 19 to 95 and 7 to 35. Both groups did not differ on the levels of cybersickness experienced during immersion in the environment (t=0.76, p=0.48; d=0.40) or after stepping out of it (t=–0.19, p=0.85; d=0.09). As was expected, reports of cybersickness during and after immersion were highly correlated (r=0.65, p=0.01).

Discussion

The purpose of this investigation was to articulate age related differences between young and old healthy adults and patients with AD on a novel measure of spatial navigation whilst also noting any qualitative differences in the ability to navigate (e.g., accuracy and precision) and recognize landmarks.

Overall, the results of this study illustrate that learning in terms of spatial navigation in both young and older healthy adults improve over successive trials. Despite this improvement demonstrated by both groups of adults, age-related differences are observed throughout trials, a finding consistent with previous studies [42,43]. The most stable age-related differences were observed in time taken to complete the task as well as the number of wrong turns participants make. To this end, computer experience as well as the ability to control the joystick could potentially influence time taken to navigate paths [42]. We insured, however, that both young and healthy older participants had an equal number of years of computer familiarity (Table 1). Unfortunately, older adults had overall less experience in playing videogames, and consequently, in joystick manipulation (Table 1). Moreover, all participants underwent a period of 5 to 10 minutes of familiarization inside a control VE to practice using our specific joystick. Participants were asked to reach a given goal inside that control environment. Once they reached that goal flawlessly, and stated they felt comfortable using the joystick, experimenters proceeded with the testing session. To this end, no significant difference in the ability to stay on the sidewalk or in the number of collisions with buildings were observed. Thus, we would tentatively conclude that participants had adequate control of the joystick, and were able to navigate the city according to the rules they were given.

With regards to qualitative differences in the ability to navigate (e.g., accuracy and precision) and recognize landmarks inconsistencies were observed across trials in the distance travelled. These discrepancies are difficult to explain although we would posit that it is likely due to the fact that rarely did participants stray very far from the prescribed path. The city was not overly large so participants were unlikely to navigate extensively before realizing they had left the path. Thus, differences across trials were fairly small. Furthermore, healthy older participants tended to scan the environment to try to find their way without actually physically moving. Thus, they didn't travel substantially far from the path even if they were lost or had made a wrong turn. We were not able to quantify the amount of scanning carried out by each group in our specific task but it would be relevant to find a way to do so in a future study. This type of behaviour was observed more frequently in elderly participants than in younger subjects, particularly in an unfamiliar environment [44]. Kirasic [44] had hypothesized that older participants have a tendency to minimize movement in order to conserve energy in a real-life setting. Our qualitative observations seem to hint that the virtual environment can mimic such a real-life effect but it remains to be seen if it will be quantifiable.

In addition, we would note the observation of increased number of wrong turns in older adults was a finding consistent with previous studies [42]. Wilkniss and her colleagues [42] mentioned that older adults experience difficulty in selecting relevant features that would help them maintain their path. These same adults also had issues with ordering these features spatiotemporally. These findings explain the increased number of mistakes that healthy older adults made when learning the paths. Cues that are sufficient for young adults to navigate flawlessly are not processed as effectively by older adults. This caused a slight but significant increase in the number of deviations from the prescribed path.

The most notable difference in our study between young and old adults was found in terms of recognition. Indeed, Kirasic [42] already showed that younger adults performed better than older adults in a scene recognition task, which was virtually identical to the task outlined in our study. In our study, healthy older adults, as well as the two patients with AD, clearly showed a tendency to erroneously affirm having seen objects or buildings that should be new to them but were equally able as young adults to correctly identify already seen objects. Kirasic [42] had suggested that the decrease in performance might be due to perceptual deficits in older adults but what would explain the discrepancy between the two types of errors? Older adults might actually be demonstrating a liberal bias (i.e. increased likelihood of answering "yes") in recognition tasks, thereby increasing the number of false positive errors. Such a bias was observed for verbal and visuospatial memory tests in patients who underwent left temporal resection [45]. Age-related changes in the left temporal lobes, particularly the hippocampus, might be the cause of this slight deficit in recognition [46].

At the same time however, it was interesting to observe that there was no significant difference in performance on the recognition task between patients with AD and healthy older people. This result is inconsistent with previous findings such as those noted by Cherrier, Mendez and Perryman [47] who demonstrated that patients with AD showed poor learning of spatial details of a newly navigated environment. It is possible however that repetitive navigation around a city, such as was performed in our task, might have provided increased familiarity and as such, aid recognition. It is just as probable, however, that this finding is merely tied to the small sample size of patients, although our obtained effect size is arguably notable. To this end, it would be pertinent to gather more data to address the reliability of this finding.

CONCLUSIONS

In summary, our study would suggest that spatial navigation is susceptible to the effects of aging consistent with previous research not utilizing novel VR based measures [48]. The results of this study do indicate a difference between young and old adults in route learning and memory. Older participants were not as fast nor as accurate as young participants during navigation. Patients with AD were variable in terms of performance when compared to older adults whilst older participants also showed a deficit in recognition of the city's objects and buildings. This deficit was equally significant in healthy older adults and in patients with AD.

The potential applications of VR to the study of spatial navigation is seemingly important in that it may help place the science of neuropsychology on firmer scientific grounds in terms of its validity to real world function and dysfunction. Moreover, it may help identify those early cognitive deficits that can aid in the early identification of patients with AD so to help slow the progression of the disease with the use of psychopharmacological agents [49,50].

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APPENDIX A

Cybersickness Questionnaire

Name of Participant:_____ **Date:**_____

Cybersickness:	Did not feel symptom				Felt symptom very strongly
Nausea	**1**	**2**	**3**	**4**	**5**
Retching	**1**	**2**	**3**	**4**	**5**
Vomiting	**1**	**2**	**3**	**4**	**5**
Eyestrain	**1**	**2**	**3**	**4**	**5**
Blurred vision	**1**	**2**	**3**	**4**	**5**
Disorientation	**1**	**2**	**3**	**4**	**5**

Dizziness (or vertigo)	**1**	**2**	**3**	**4**	**5**
Sweating	**1**	**2**	**3**	**4**	**5**
Headache	**1**	**2**	**3**	**4**	**5**
Increased salivation	**1**	**2**	**3**	**4**	**5**
Feeling that you need to burp	**1**	**2**	**3**	**4**	**5**
Light-headedness	**1**	**2**	**3**	**4**	**5**
Yawning	**1**	**2**	**3**	**4**	**5**
Loss of appetite	**1**	**2**	**3**	**4**	**5**
Stomach awareness	**1**	**2**	**3**	**4**	**5**
Depression	**1**	**2**	**3**	**4**	**5**
Apathy	**1**	**2**	**3**	**4**	**5**
Difficulty concentrating & focusing	**1**	**2**	**3**	**4**	**5**
Overall confusion	**1**	**2**	**3**	**4**	**5**
Aftereffects*:*					
Disturbed locomotion	**1**	**2**	**3**	**4**	**5**
Loss of postural stability	**1**	**2**	**3**	**4**	**5**
Sensation of continued motion	**1**	**2**	**3**	**4**	**5**
Visual flashbacks	**1**	**2**	**3**	**4**	**5**
Drowsiness	**1**	**2**	**3**	**4**	**5**
Fatigue	**1**	**2**	**3**	**4**	**5**
Lowered arousal	**1**	**2**	**3**	**4**	**5**

Have you ever had problems with:

Airsickness _____ Carsickness _____ Seasickness _____

Swing sickness _____

No problems with motion sickness in the past (please check here) _____

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