Virtual Reality (2014) 18:271–279
DOI 10.1007/s10055-014-0252-2

ORIGINAL ARTICLE

Using a virtual environment to assess cognition in the elderly

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Received: 27 November 2013 / Accepted: 17 September 2014 / Published online: 26 September 2014

Abstract Early diagnosis of Alzheimer's disease (AD) is essential if treatments are to be administered at an earlier point in time before neurons degenerate to a stage beyond repair. In order for early detection to occur tools used to detect the disorder must be sensitive to the earliest of cognitive impairments. Virtual reality technology offers opportunities to provide products which attempt to mimic daily life situations, as much as is possible, within the computational environment. This may be useful for the detection of cognitive difficulties. We develop a virtual simulation designed to assess visuospatial memory in order to investigate cognitive function in a group of healthy elderly participants and those with a mild cognitive impairment (MCI). Participants were required to guide themselves along a virtual path to reach a virtual destination which they were required to remember. The preliminary results indicate that this virtual simulation has the potential to be used for detection of early AD since significant correlations of scores on the virtual environment with existing neuropsychological tests were found. Furthermore, the test discriminated between healthy elderly participants and those with a MCI.

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Keywords Virtual reality · Spatial memory · Mild cognitive impairment · Spatial navigation

1 Introduction

Computer technology has progressed to a level where virtual environments can be used to mimic everyday tasks. Virtual reality (VR) is a technology used in many applications, from the arts to health care such as arachnophobia (Garcia-Palacios et al. 2002), fear of flying (Banos et al. 2002), acrophobia (Coelho et al. 2009), fear of public speaking (Slater et al. 2006) and motor rehabilitation (Holden 2005). VR provides the opportunity to simulate real-world environments and/or activities and can be of use for patients in rehabilitation settings (Marques et al. 2008). VR environments have been created to assess components of cognition, specifically spatial memory and route learning, which are tasks that may be useful in the detection of cognitive difficulties associated with dementia.

Alzheimer's disease (AD) is the most common form of dementia and is a progressive neurodegenerative disorder (Hettinga et al. 2009). The most well-known symptom of AD is memory loss which worsens over time (Hettinga et al. 2009). An effective treatment or cure remains elusive and the incidence of the disease continues to increase (Singh-Manoux and Kivimäki 2010). Mild cognitive impairment (MCI) is widely believed to be a transitional stage between normal ageing and AD (Petersen et al. 2001). According to Petersen (2011), MCI has an estimated prevalence of between 10 and 20 % of individuals over the age of 65 in population-based studies (Petersen 2011). There is a large focus in AD research to try to detect and diagnose the disease as early as possible (Petersen et al. 2001; Forlenza et al. 2010). As a result, research studies have focused on the evaluation of whether cognitive tests can discriminate with accuracy between the healthy elderly (HE), AD and MCI participants (Chandler et al. 2008; de Jager et al. 2008). Studies which have recruited MCI participants have demonstrated that these individuals possess impairments in route learning (Klein et al. 1999). MCI patients have, on imaging scans, presented with an elevated volumetric decline in the entorhinal cortex (EC) of the hippocampus in the medial temporal lobe, an area responsible for processing spatial memory (Dubois et al. 2007). Imaging techniques and lesion studies carried out in combination have shown that this deterioration occurs early in the disease pathway, and therefore, tests which are sensitive to spatial memory and route learning should show deficiencies in performance if this area is affected.

Given that more and more elderly participants are familiar with computer use, a logical next step in the field of diagnosis of a memory impairment or cognitive complaint is the implementation of virtual forms of assessment. For example, clear navigational deficits are seen in AD patients and this leads to sufferers getting lost, wandering, and taking the wrong direction on car journeys. This has potentially devastating consequences and causes significant worry for the carers and families involved. Few well-established tests for assessing navigational deficits early on in the disease trajectory exist at present.

Cherrier et al. (2001) investigated topographical dysfunction (topographical memory is, for example, memory for a journey taken) of performance measurement in AD patients in comparison with cognitively HE controls by asking participants to complete an outdoor route task accompanied by a researcher. The aim of the study was to determine whether AD patients experienced problems with spatial orientation rather than an inability to recall the location of landmarks along the route. The results showed that the AD patients demonstrated poor performance in comparison with controls due to poor spatial orientation and reasoning (Cherrier et al. 2001). If this type of assessment could be carried out virtually, it may result in a more practical and efficient procedure of testing human participants. Furthermore, VR offers some advantages over standard pen and paper assessments of spatial memory or real-world route learning tasks. For example, VR gives the experimenter control over the number and the type of stimuli the environment contains as well as control over the complexity which allows them to observe the participants response in more detail. Similarly using a computerised system allows for the accurate recording of data and the number of errors made without the reliance of subjective assessments and note taking from a researcher.

Furthermore, pen and paper tests of spatial navigation have been criticised for their lack of ecological validity which limits their reliability for comparisons to real-world navigational difficulties (Werner et al. 2009). Virtual environments provide the user with a high level of immersion, and subjects often report that they felt as though they were actually within the 'game' or 'scene' which can cover a much larger spatial area than standard tests (Duffy 2009). Virtual tasks are also more useful than real-world navigational tasks which, although they may be better than standard pen and paper tasks, can be impractical as they often rely on public areas such as a hospital foyer, or the floor of a building. These places are likely to change on a daily basis in terms of the number and presence of others, level of noise, smell and sound (Pengas et al. 2010).

Previously, Werner et al. (2009) developed a virtual supermarket to examine the feasibility and the validity of a virtual action planning supermarket (VAP-S) for the diagnosis of patients with a MCI (Werner et al. 2009). This experiment asked participants to purchase seven items from a list and pay for these at the virtual counter. Score on the VAP-S alone was not able to discriminate between MCI participants and controls; however, combining VAP-S score with score on another very common tool used in the diagnosis of cognitive impairment, namely the mini-mental state examination (MMSE), was able to differentiate successfully between the patient groups. Similarly, Pengas et al. (2010) used a virtual environment with the aim to discriminate between AD patients, controls and semantic dementia patients (Pengas et al. 2010). Topographical memory was assessed using tasks that included the virtual route learning test (VRLT). The results demonstrated that the score on the VRLT achieved 95 % sensitivity which is the true positive rate, i.e. the positive scores obtained that were correctly classed as positive and 94 % specificity which is the 'true' negative score, i.e. the number of negatives obtained that were correctly classed as negative in discriminating AD patients from controls (Pengas et al. 2010).

Another study by Tippett et al. (2009) examined behavioural performance across different populations using a virtual environment. This study was unable to discriminate between MCI and cognitively normal controls. Cushman et al. (2008) investigated the efficacy of using a VR environment when assessing navigational performance in participants with early AD and MCI along with young adults and older controls (Cushman et al. 2008). Their results revealed correlations between real-world navigational deficits and those from the VR environment in all groups, highlighting the potential efficacy of using VR as a test for dementia. None of the measures, however, predicted which diagnostic group the participant belonged to (Cushman et al. 2008).

The aim of the study was to evaluate the use of our newly developed VR test as a potential tool to be used for the early detection of AD. The VR test is based on topographical memory in order to determine whether score on this assessment can discriminate between HE participants and individuals classified as MCI. Furthermore, the study also compares scores on the VR assessment with existing neuropsychological tests as these are commonly used in the diagnosis of cognitive impairment (Jacova et al. 2007). It is therefore important to evaluate its potential against current established screening measures.

2 Methods

2.1 Participants

The participant cohort consisted of 31 participants: 10 males and 21 females. All participants had no existing neurological disorder or a clinically diagnosed memory impairment. Furthermore, none of the participants had an uncorrectable visual impairment. All participants were recruited from the University of Bradford, Division of Psychology over-60s participant pool. The study was approved by the University of Bradford Ethics Committee. Of the 31 participants enrolled, nine were classified as MCI. As this was the first time that the VREAD has been piloted in elderly cognitive research, recruiting a sample size of 30 is reasonable. Previous research which has piloted virtual environments for use as cognitive tools in the elderly has used similar sample sizes. For example Cushman et al. (2008) recruited 26 elderly participants, Tippett et al. (2009) recruited 26 elderly participants, and Pengas et al. (2012) recruited 30 participants with AD. Whilst we acknowledge that the number of MCI participants was small, when recruiting participants with no clinical diagnosis of a cognitive impairment, it would be expected that 8–10 % of the sample would be defined as mild cognitively impaired (Petersen et al. 2001).

2.2 VE experimental apparatus

2.2.1 Virtual reality for early detection of Alzheimer's disease (VREAD)

The experimental environment operates on a standard PC and simulates two fully textured versions of various scenes. VR for early detection of Alzheimer's Disease, known as VREAD, consists of three modules: VR practice, VR park and VR games (see Fig. 1). The name of VREAD was chosen as the overarching aim is to develop a test for the early detection of AD.

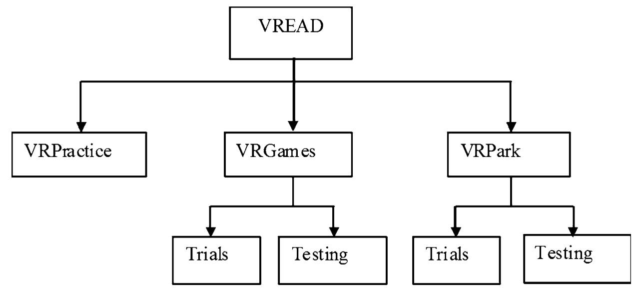

Fig. 1 Overview of VREAD

2.3 Procedures of VREAD

Participants' information was recorded onto the system. A unique user ID was given to each participant. Each participant was trained to use the arrow keys of a standard key board using the VR Practice Module (the keys needed to carry out the test). Following this, the participants were able to see one of the two modules VR Park or VR Games. The participants repeated the exercise of reaching the target destination three times by following the red lines attached to the path. In this simulation, there were five different levels of difficulty ranging from easy to complex. Level 1 was considered to be the easiest with each level getting progressively harder requiring more complex navigation. The levels of difficulty were defined based on junctions, paths and target destinations in each route which users had to achieve in the testing phase. Additionally, extra destinations were added as a 'dummy' to make the path more complex and difficult. This implementation allowed the research to investigate the users' task performance in each level. VR Park had the target destination of a park layout which included a playground, picnic area, art gallery, park squares and mini garden. For the second module, VR Games had the target destination of outdoor games activities such as a giant chess board, giant board games, lawn bowls, mini golf and a picnic area. Both modules had the same number of levels and landmarks, and VR Park's path was mirrored to VR Games' path. Pilot testing showed that the VR scores, which equated to a percentage correct value out of a possible 100 %, were significantly worse on VR Park, and so we continued with just this version.

Next, the participant was tested on their ability to recollect the given path. All data were collected and recorded during this phase. Lastly, all data were exported to the information system to be analysed. See Figs. 2 and 3 for screenshots of the VR environment.

2.3.1 Movement measures in the VR environment

Movement measures in the environment were based on path squares, which consisted of underlying grids unknown to users. These path squares were numbered and were used to calculate the scores. During the testing phase, data were collected automatically in real time comprising the following five attributes: (1) correct path, (2) incorrect path,

Fig. 2 Scenes from VREAD

Fig. 3 Scenes from VREAD

(3) correct sequences, (4) incorrect sequences and (5) time. Scores were calculated based on path sequences and path squares. An overall percentage score was calculated based on the numbers of correct path squares and number of correct sequences obtained on the unseen grid beneath.

2.4 Neuropsychological tests

A battery of neuropsychological tests was given to participants assessing multiple cognitive domains to obtain a profile of their cognitive function. The following tests were administered:

2.4.1 Graded naming test (GNT)

The GNT assesses semantic memory and was developed as an instrument to detect mild word retrieval difficulties (McKenna and Warrington 1980). Participants must identify 30 black and white line drawings presented on a computer screen.

2.4.2 CANTAB paired associate learning test (CANTAB PAL)

The CANTAB PAL is an assessment of visuospatial associative memory and requires the participant to learn an association between a visual stimulus and a spatial location (Égerházi et al. 2007). The test is delivered via a touch screen computer and takes approximately 10 min to administer. The participant is presented with a screen showing six white boxes which open up in a random order, and they are asked to remember which box a pattern appears in. They are then required to remember the location of two different patterns, then three and then six. The number of errors made at the six-pattern stage is thought to be sensitive to MCI and early AD (Blackwell et al. 2004).

Blackwell et al. (2004) created an algorithm using the PAL 6 error score, score on the GNT and age to accurately identify converters to AD with 100 % accuracy within a 32-month period for a sample of 40 patients (Blackwell et al. 2004).

2.4.3 Mini-mental state examination (MMSE)

The MMSE is an assessment of general cognitive function which includes a number of questions which target different cognitive domains such as orientation, short-term memory, recall, language, attention, copying and verbal understanding (Folstein et al. 1975). The test takes approximately 10 min to complete and is described as a 'quick' test of general cognitive ability (Jacova et al. 2007; Petersen 2011). The participant receives a score out of a possible 30. A score of 24 or above signifies no impairment is present, 18–23 represents a mild impairment and 0–17 signifies a severe impairment in cognitive function. The test is particularly poor at detecting mild cases of impairment which is problematic for patients who score on the borderline.

2.4.4 Word recall

Word recall is an assessment of short-term memory and typically involves reading the participant a list of common nouns and then asking them to repeat back as many as possible. A score out of 15 was given; one point per correct word recalled.

2.5 Questionnaires

Participants were requested to complete a VREAD feedback questionnaire. This was aimed at the users' acceptance and satisfaction of the virtual environment. The questionnaire specifically asked participants whether they possessed prior experience of using computers and or games as well as assessing the participants' (1) ease of learning the controls, (2) ease of movement, (3) ability to understand the instructions and (4) freedom of movement. Easy use of the virtual environment is essential if this is to become an established test. Results of the feedback questionnaire and the participants' satisfaction of the VR test are discussed in Wan Shamsuddin et al. (2011a, b).

3 Results

The aim of the study was to evaluate the use of the VREAD test as a potential tool to be used for the early detection of AD. Each participant completed a battery of neuropsychological assessments as well as the VREAD test. Studies which utilise neuropsychological testing as a part of their methodology should check that the results obtained are not significantly influenced by the participant's age or gender. Research has noted that age and gender can significantly skew scores obtained (Jacova et al. 2007; Fields et al. 2011) and, therefore, to ensure that the results obtained in the current study were not a result of an age effect within the sample we have investigated these factors in our results. Previous computer experience is also a logical and important factor to investigate that could have influenced scores as VREAD is a computerised test. The descriptive statistics for the participants (subcategorised into HE and MCI) can be seen in Table 1, and the descriptive statistics for each test are shown in Tables 2 and 3, respectively.

Independent samples *t* tests revealed that there were no significant differences between the HE or MCI participants

Table 1 Demographics for those participants classified as HE and MCI

Characteristics	HE ($n = 22$)	MCI ($n = 9$)
Age, years (mean ± SD)	69.77 (4.60)	72.67 (6.56)
Gender (M:F)	5:17	5:4
Education, years (mean ± SD)	15.50 (6.04)	20.07 (6.26)
Possessed previous computer experience	6	2

Table 2 The mean and standard deviations (SDs) for each neuropsychological assessment

Test	*N*	Min	Max	Mean	SD
MMSE	31	26	30	28.84	1.21
Word recall	31	3	10	5.55	1.84
PAL 6 errors	31	0	49	10.13	11.14
GNT	30	19	30	25.90	3.14

One participant did not complete the GNT

Table 3 The mean and SDs for each level of the VREAD assessment

Level	*N*	Min (%)	Max (%)	Mean (%)	SD
1	31	60	100	97.90	8.34
2	31	6.41	100	93.00	23.42
3	31	41.67	100	95.06	12.98
4	31	19.35	100	94.60	16.92
5	31	56	100	89.80	13.56

in terms of age or years in education ($p > 0.05$). A chi-square test showed that there was no significant difference in the gender distribution between the two diagnostic categories.

Although the levels of the VREAD were designed to increase in difficulty the results in Table 3 do not reflect this. The results of all the VREAD levels and all neuropsychological tests (MMSE, CANTAB PAL 6 error score, GNT and word recall) were submitted to a correlational analysis using SPSS. Of the five levels of the VR study, level four (VR 4) significantly correlated with participants' score on both the CANTAB PAL six-pattern stage and the GNT, $r = -0.45$ $p < 0.02$ and $r = 0.43$, $p < 0.02$, respectively. No significance was seen for the MMSE score. No other level of the task significantly correlated with any of the cognitive tests administered. Scatter plots for these significant associations are shown in Figs. 4 and 5.

A general linear model univariate analysis of variance was used to investigate the effects of age, gender and education on the scores of VR 4. None were significant. A multivariate analysis was used to investigate age, gender and education on the neuropsychological tests, and again no significance was found.

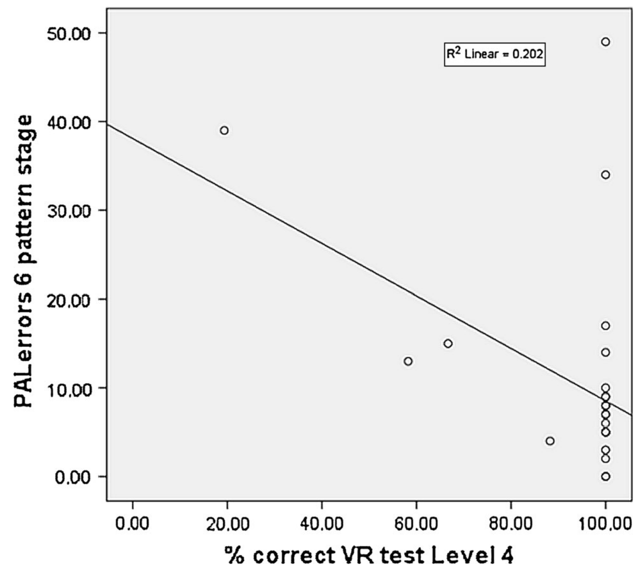

Fig. 4 Participant's error scores on the six-pattern stage of the CANTAB PAL and VR 4. As can be seen from the graph, as the number of errors on the PAL six-pattern stage decreased performance on VR 4 increased

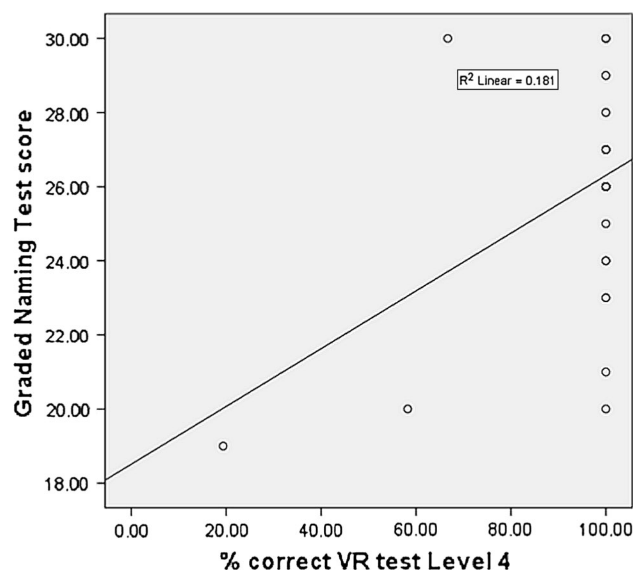

Fig. 5 Scores on the GNT against VR 4 score. As the number of correctly identified pictures on the GNT increases so does VR 4 score

3.1 Discrimination between Groups

In total, there were 22 HE participants and nine MCI. Figure 6 below shows that the mean score for VR 4 was lower in the MCI group compared with the HE group. An independent samples *t* test shows that this difference was

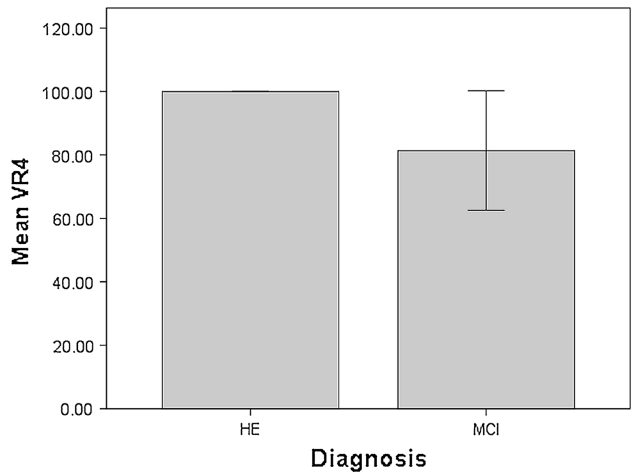

Fig. 6 Mean VR 4 scores for HE and MCI participants

significant $t(29) = 3.17$, $p < 0.01$, confirming that score on VR 4 could discriminate between the two patient groups.

3.2 Previous computer experience

Eight participants had previous VR experience (two of these participants were classified as MCI). An independent samples t test carried out between those that had previous VR experience and those that had not was non-significant, $p > 0.05$.

4 Discussion

The aim of the present study was to investigate whether a new VR environment could be used as a novel test of visuospatial associative memory useful for investigating cognition in the elderly, and how this correlates with established neuropsychological tests of cognitive function for this age group. The overarching aim is to use this test as a method for the early diagnosis of AD.

VR is becoming a useful method for assessing participants on a wide range of tasks particularly in the health care domain with a specific emphasis on navigational difficulties (Rizzo and Kim 2005). In the present study, participants carried out five levels of VREAD and the results showed that percentage correct scores on VR 4 significantly correlated with the CANTAB PAL six-pattern error score and score on the GNT. Score on VR 4 did not correlate with participants' MMSE score which is important as the MMSE is not sensitive to mild degrees of cognitive impairment (Pasquier 1999; Cullum et al. 2000; de Jager et al. 2008). In addition, the score on VR 4 was able to successfully identify participants according to whether they were HE or MCI.

The CANTAB PAL six-pattern error score and the GNT score, combined with the participant's age, were used in a study by Blackwell et al. (2004). The three factors were entered into a regression analysis, and the algorithm was able to predict with an accuracy of 100 % which participants converted to AD and those that stayed as questionable dementia over a 32-month period. The VR 4 scores in the present study correlated with these two tests but showed no effect of age, suggesting that VR 4 could be used as a more straightforward method of testing cognition and cognitive decline. There are no results yet on decline or prediction of decline using the present VREAD test, but this is the next logical area of study.

Previous research has reported that poorer performance may simply be a result of increasing age in the sample (Tombaugh and McIntyre 1992). The results of our study, however, demonstrate that age was not significantly correlated with score on VR 4. Likewise participant's score at this level revealed no correlation with MMSE score. Baseline score in the MMSE can vary immensely; Blackwell et al. (2004) found that in a group of AD convertors, baseline score varied from between 23 and 28 (Blackwell et al. 2004). Individuals scoring 28 would have been classified as cognitively normal, and this is problematic as their score does not correlate with underlying changes in brain pathology. The National Institute for Health and Clinical Excellence (NICE) guidelines currently use MMSE score to determine whether a patient receives pharmacological treatment (Dening 2009). Furthermore the accuracy and reliability of the MMSE can be affected by mood, time of day, education and age (Jacova et al. 2007).

An important quality of neuropsychological tests should be their ability to correctly identify a participant's clinical group. Score obtained on VR 4 was significantly worse in those participants classified as MCI in comparison with the HE confirming that this novel assessment can discriminate reliably between the two groups. This has implications in terms of using this particular test as a potential screening tool for the detection of MCI or early AD. However, it is clear from the results of this iteration that a number of participants scored 100 % which could potentially be obscuring participants that have a more subtle impairment. The results do still successfully discriminate between groups, but future study will involve making the VREAD test harder to avoid this.

It remains unclear why VR 4 was the level which correlated with the scores obtained on the neuropsychological tests. Each level became progressively harder based on number of turns and number of objects such as trees, benches, street lights, fences and buildings. The overarching aim is to have a simple test with one level and this is the next stage of our research.

In some previous investigations, researchers have raised concern about the possible side effects of using a virtual world which have included participants reporting feelings of disorientation or nausea during the task (Moffat et al. 2001). This was not problematic in our study and there were no reports of illness, headaches or nausea as assessed by the usability questionnaire (Wan Shamsuddin et al. 2011a, b).

Previous criticisms of the virtual environment have included the issue of extrapolation to the real world and whether or not a false 'world' can be thought of as a reliable way to learn and encode newly formed routes or cognitive maps. Some participants reported that they found the test too easy and stated that they did not feel they required three practice attempts at each trial. Each level of the VREAD was designed to increase in difficulty and complexity; however, the results do not reflect this, suggesting there may be a potential learning effect. This will require further study and adjustment. None of the participants commented that they were unable to use the apparatus and each individual was allowed a practice session prior to commencing the actual assessment so as to familiarise themselves with the keyboard and virtual world. Those who possessed prior use of games consoles or computer gaming devices may have moved more fluently through the test, but this did not contribute to their ability to memorise and learn each route. This, however, may change when a harder version is created.

5 Conclusion

Self-report of navigational deficits is common in the elderly and the ability to encode and remember new routes is impaired in those individuals who have a cognitive impairment. In the present study, we found that using a newly developed VR-based assessment for spatial memory could be used as a possible method for the detection of a cognitive impairment. Significant correlations were found between VR 4, the CANTAB PAL 6 error score and the GNT. Additionally, there was no association with the MMSE which has previously been criticised for its inability to detect mild changes in cognition (Pasquier 1999; Cullum et al. 2000; de Jager et al. 2008). VR 4 also discriminated between HE and MCI participants. Future study will investigate whether the VR test can predict decline to AD. Furthermore, the sample size of 31 participants with nine of these having MCI is too small, along with the high ceiling effect, to verify the utility of the test in a clinical setting at present, but given these preliminary results further study will aim to achieve this.

Acknowledgments The authors would like to express their gratitude to the School of Computing, Informatics and Media, School of Social and International Studies, Rebecca Durrans in the Division of Psychology, University of Bradford and University of Sultan Zainal Abidin (UniSZA) for the support and facilities provided. We also thank Nick Farrar from Adult and Community Services at Bradford Metropolitan District Council and all the participants for taking part.

References

Banos RM, Botella C, Perpiñá C, Alcañiz M, Lozano JA, Osma J, Gallardo M (2002) Virtual reality treatment of flying phobia. IEEE Trans Inf Technol Biomed 6:206–212

Blackwell A, Sahakian B, Vesey R, Semple J, Robbins T, Hodges J (2004) Detecting dementia: novel neuropsychological markers of preclinical Alzheimer's disease. Dement Geriatr Cogn Disord 17:42–48

Chandler JM, Marsico M, Harper-Mozley L, Vogt R, Peng Y, Lesk VE, De Jager CA (2008) Cognitive assessment: discrimination of impairment and detection of decline in Alzheimer's disease and mild cognitive impairment. Alzheimers Dement 4:T551–T552

Cherrier M, Mendez M, Perryman K (2001) Route learning performance in Alzheimer disease patients. Cogn Behav Neurol 14:159–168

Coelho CM, Waters AM, Hine TJ, Wallis G (2009) The use of virtual reality in acrophobia research and treatment. J Anxiety Disord 23:563–574

Cullum S, Huppert FA, Mcgee M, Dening T, Ahmed A, Paykel ES, Brayne C (2000) Decline across different domains of cognitive function in normal ageing: results of a longitudinal population-based study using Camcog. Int J Geriatr Psychiatr 15:853–862

Cushman LA, Stein K, Duffy CJ (2008) Detecting navigational deficits in cognitive aging and alzheimer disease using virtual reality. Neurology 71:888–895

De Jager CA, Lesk VE, Zhu X, Marsico M, Chandler J (2008) Episodic memory test constructs affect discrimination between healthy elderly and cases with mild cognitive impairment and Alzheimer's disease. Alzheimers Dement 4:T554–T555

Dening T (2009) Prescribing policy with dementia drugs: the UK nice experience. Maturitas 64:59–60

Dubois B, Feldman HH, Jacova C, Dekosky ST, Barberger-Gateau P, Cummings J, Scheltens P (2007) Research criteria for the diagnosis of Alzheimer's disease: revising the Nincds–Adrda criteria. Lancet Neurol 6:734–746

Duffy CJ (2009) Visual motion processing in aging and Alzheimer's disease. Ann N Y Acad Sci 1170:736–744

Égerházi A, Berecz R, Bartók E, Degrell I (2007) Automated neuropsychological test battery (Cantab) in mild cognitive impairment and in Alzheimer's disease. Prog Neuropsychopharmacol Biol Psychiatry 3:746–751

Fields JA, Ferman TJ, Boeve BF, Smith GE (2011) Neuropsychological assessment of patients with dementing illness. Nat Rev Neurosci 7:677–687

Folstein MF, Folstein SE, Mchugh PR (1975) Mini-mental state: a practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 12:189–198

Forlenza OV, Diniz BS, Gattaz WF (2010) Diagnosis and biomarkers of predementia in Alzheimer's disease. BMC Med 8:1741–7015

Garcia-Palacios A, Hoffman H, Carlin A, Furness T, Botella C (2002) Virtual reality in the treatment of spider phobia: a controlled study. Behav Res Ther 40:983–993

Hettinga M, De Boer J, Goldberg E, Moelaert F (2009) Navigation for people with mild dementia. Stud Health Technol Inform 150:428–432

Holden MK (2005) Virtual environments for motor rehabilitation: review. CyberPsychol Behav 8:187–211

Jacova C, Kertesz A, Blair M, Fisk JD, Feldman HH (2007) Neuropsychological testing and assessment for dementia. Alzheimer's Dement 3:299–317

Klein D, Steinberg M, Galik E, Steele C, Sheppard J, Warren A, Lyketsos C (1999) Wandering behaviour in community-residing persons with dementia. Int J Geriatr Psychiat 14:272–279

Marques A, Queirós C, Rocha N (2008) Virtual reality and neuropsychology: a cognitive rehabilitation approach for people with psychiatric disabilities. In: Sharkey P, Lopes Santos PL, Weiss P, Brooks T (eds) ICDVRAT – Proceedings of 7th International Conference on Disability Virtual Reality and Associated Technologies, 8–11 Sep 2008. Maia, Portugal, pp 39–46

McKenna P, Warrington EK (1980) Testing for nominal dysphasia. J Neurol Neurosurg Psychiatry 43:781–788

Moffat SD, Zonderman AB, Resnick SM (2001) Age differences in spatial memory in a virtual environment navigation task. Neurobiol Aging 22:787–796

Pasquier F (1999) Early diagnosis of dementia: neuropsychology. J Neurol 246:6–15

Pengas G, Patterson K, Arnold RJ, Bird CM, Burgess N, Nestor PJ (2010) Lost and found: bespoke memory testing for Alzheimer's disease and semantic dementia. J Alzheimer's Dis 21:1347–1365

Pengas G, Williams GB, Acosta-Cabronero J, Ash TW, Hong YT, Izquierdo-Garcia D, Fryer TD, Hodges JR, Nestor PJ (2012) The relationship of topographical memory performance to regional neurodegeneration in Alzheimer's disease. Front Aging Neurosci 4:17

Petersen RC (2011) Mild cognitive impairment. N Engl J Med 364:2227–2234

Petersen RC, Doody R, Kurz A, Mohs RC, Morris JC, Rabins PV, Winblad B (2001) Current concepts in mild cognitive impairment. Arch Neurol 58:1985–1992

Rizzo AS, Kim GJ (2005) A swot analysis of the field of virtual reality rehabilitation and therapy. Presence Teleop Virtual Environ 14:119–146

Singh-Manoux A, Kivimäki M (2010) The importance of cognitive ageing for understanding dementia. Age 32:509–512

Slater M, Pertaub DP, Barker C, Clark DM (2006) An experimental study on fear of public speaking using a virtual environment. CyberPsychol Behav 9:627–633

Tippett WJ, Lee JH, Zakzanis KK, Black SE, Mraz R, Graham SJ (2009) Visually navigating a virtual world with real-world impairments: a study of visually and spatially guided performance in individuals with mild cognitive impairments. J Clin Exp Neuropsychol 31:447–454

Tombaugh TN, McIntyre NJ (1992) The mini-mental state examination: a comprehensive review. J Am Geriatr Soc 40:922–935

Wan Shamsuddin S, Ugail H, Lesk VE (2011a) Development and usability evaluation of virtual environment for early diagnosis of dementia. In: Proceedings of the 2nd visual informatics: sustaining research and innovations, pp 13–22

Wan Shamsuddin S, Walters ER, Ugail H, Lesk VE (2011b) Evaluation of users acceptance in virtual environment for early diagnosis of dementia. Paper presented at world conference on information technology, Antalya Turkey

Werner P, Rabinowitz S, Klinger E, Korczyn AD, Josman N (2009) Use of the virtual action planning supermarket for the diagnosis of mild cognitive impairment. Dement Geriatr Cogn Disord 27:301–309