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Predictors of performance in real and virtual scenarios across age

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Background: Virtual reality applications to assist older adult with cognitive and functional decline are fast growing. However, such technological developments face limitations such as due to limited constructs and ecological validity. This study was aimed at investigating age-related changes in functional abilities and their associated cognitive underpinnings during task performance in virtual and real environments.

Method: Twenty-two younger adults (university students) and twenty-two older adults (aged 58-74) performed a multiple errands task twice, once in the 'Discoveries' section of the National Museum of Scotland and once in the same room as a virtual environment. Accuracy and distance travelled were measured in both groups. Cognitive and daily living abilities were recorded in older adults using standard and novel questionnaires.

Results: The testing environment had a significant effect on how efficient individuals performed the task. Older and younger adults' performance was alike but older adults relied on more cognitive resources. Older adults struggled in the virtual but not in the real environment. Younger but not older adults could transfer knowledge between environments.

Conclusion: The use of technology to assist frail older adults and those affected by dementia is growing rapidly. For these novel tools to be theoretically valid, they need to incorporate knowledge of the challenges they pose to these vulnerable groups. Here we present evidence of such challenges and their cognitive underpinnings. This theory may be considered by future applications aimed at enhancing functional abilities in these populations.

Keywords: virtual reality; cognitive ageing; ecological validity; knowledge transfer; assistive technology

Introduction

Technological advancements in the last few decades, particularly in the area of virtual reality (VR) technologies, are creating new opportunities to investigate how people function in their day-to-day lives and how cognition supports complex adaptive behaviours (Gregg & Tarrier, 2007; Riva, 2004). Although reliable, traditional methods used to investigate, assess, and rehabilitate cognitive abilities lack strong construct validity limiting their scope to interpret how people function in real-world situations (Robert et al., 2013). Hence, they too lack strong ecological validity. Technological advances are helping to overcome such limitations by providing researchers with tools to develop VR scenarios wherein people can function akin to everyday life situations (Allain et al., 2014; Craik & Bialystok, 2006; Plancher, Gyselinck, Nicolas, & Piolino, 2010; Tost et al., 2009; Weniger, Ruhleder, Lange, Wolf, & Irle, 2011). A summary of previous research utilizing VR technology to study cognitive abilities is presented in Table 1.

[Insert Table 1 near here]

Among the features that make VR an appealing tool is the ability to create dynamic two/three-dimensional virtual environments (VEs) wherein users navigate through realistic spaces and interact with various stimuli as they would in a real-world situation (Krch et al., 2013; Lalonde, Henry, Drouin-Germain, Nolin, & Beauchamp, 2013). From a research and more applied perspective (i.e., rehabilitation), this creates opportunities to develop scenarios with high ecological validity, while the researcher retains a great deal of experimental control (Josman et al., 2014). However, these new tools still face limitations. Pertinent to this study are VR’s construct validity, ecological validity, and sensitivity to healthy cognitive ageing. An overwhelming number of studies utilizing VR technology do not have an underlying theory, and therefore, lack construct validity. Logie, Law, Trawley, and Nissan (2010) have attempted to overcome this limitation by use of structural equation modelling to develop a theory of everyday multitasking using the Edinburgh Virtual Errands Test (EVET) that identified memory, planning, and intent (or prospective memory) as the necessary components. The authors showed that planning and memory drive intent, but only memory drives planning. This theory was the basis for their subsequent research on multitasking and its cognitive components (Law et al., 2013; Logie et al., 2011; Trawley et al., 2011). Such a theory provided the basis for the VR platform developed for the current study.

Additionally, despite claims that VR tools hold a high ecological validity, available approaches to incorporate such methodologies in intervention programs suggest that such claims may not be entirely tenable. To be considered ecologically valid, skills developed from VR tools should lead to better real-world abilities. A still limited ecological validity could explain why benefits drawn from VR-based intervention programs barely outlast the duration of such programs (Fritz, Peters, Merlo, & Donley, 2013; Kozak, Hancock, Arthur, & Chrysler, 1993; Mendes et al., 2012; Yang, Tsai, Chuang, Sung, & Wang, 2008). A potential factor limiting the retention of such benefits could be the possibility that these programs or tools have not enabled the transfer of knowledge or re-acquired skills from VR rehabilitation to real-world daily living environments (Koenig et al., 2011; Richardson et al., 1999; Ruddle et al., 1997). A possible solution to this would be to develop VEs that mimic real life environments. By customizing VEs, an individualized approach to intervention could be adopted rendering such intervention truly ecological. In the present study we investigated the feasibility of such an approach.

Finally, it is unclear if the age-related impact on performance during tasks carried out in VEs is above and beyond that seen in real life settings. Logie, Law, Trawley, and Nissan (2009) showed that increased age negatively impacted performance on a simulated breakfast task. When the researchers ran a real-world version of the breakfast task, they still found an age effect but it is was much smaller than that seen with the simulated task (Logie et al., 2010). This suggests that computer simulated tasks pose greater challenges to older adults than similar real life tasks (Anguera et al., 2013). This issue is relevant if we consider that such technologies are being incorporated in programs aimed at boosting cognitive abilities in healthy elderly people (Bisson, Contant, Sveistrup, & Lajoie, 2007; Legault et al., 2013) or restoring such abilities in those experiencing cognitive decline (e.g., dementia) (Cameirao et al., 2010; Tost et al., 2009).

The principal aim of this study was to compare performance on a multiple errands task between VR and real-world testing environments and across age in healthy adults. Based on previous research, we expected all participants to perform slightly worse in the VE (Allain et al., 2014; Cushman et al., 2008). Navigational deficits are common in healthy older adults (Anguera et al., 2013; Klencklen, Despres, & Dufour, 2012). Thus, we hypothesized that performance would decrease with age. Furthermore, we aimed to identify specific variables that can predict such performance and determine if these variables change with age. For older adults, we additionally wanted to investigate whether variables sensitive to age-related cognitive decline can predict performance on this task and whether the effect is consistent between testing environments.

Method

Participants

A sample of 44 adults (22 older and 22 younger), who self-identified as healthy participated in this study. Younger participants were students at the University of Edinburgh. Older participants, aged 58-74, were recruited via the Psychology Volunteer panel. All procedures were approved by the University of Edinburgh Psychology Ethics Committee. Written informed consent was obtained prior to participation and participants were paid £7 for their contribution. Older participants were screened for potential cognitive dysfunction using the Addenbrooke's Cognitive Examination-III (ACE-III). One older participant had an ACE-III total score below the cut-off of 88 and was excluded from analysis (Law et al., 2013). The groups were matched for education; however, the ratio of females to males was greater in the younger group (18:4) than in the older group (11:10). Demographic characteristics of all participants and ACE-III scores from the older group are presented in Table 2.

Assessment

Informatics Technology (IT) familiarity

All participants were given an IT questionnaire to assess familiarity with four types of technology: computers, tablets, smartphones, and gaming consoles. Participants were asked for how many years they have used each type of technology and to endorse on a scale of 0-3 (0=not applicable, 3= frequently) how often they perform various tasks (see Supplementary Material 1 for the questionnaire). An experience score was calculated by summing the frequency scores for each technology type. A ratio score was calculated by dividing years of use by the experience score for each technology type. This ratio reflects the overall familiarity each participant has with the technology. Additionally, overall IT scores, which were the sum of the four types of technology, were calculated for each participant. Data from both age groups on the IT questionnaire is presented in Table 3.

Functions of everyday life

Older adults were given a questionnaire about activities of everyday life (see Supplementary Material 2 for the questionnaire). This questionnaire consists of 82 statements that gauge how much difficulty a person has functioning in daily life. Participants were asked to endorse on a scale of 0-3 (0=not applicable, 3=frequently) how often they experience each statement. A daily living function (DLF) percentage was calculated for each participant using the equation DLF %= (Total Score / Maximum Score) x 100, where Maximum Score corresponds to the number of questions answered x 3, and the Total Score is the sum of answered questions. Questions endorsed as 0 (i.e. not applicable) were not included in the calculations. Higher percentages reflect more impairment in daily living functions. DLF percentages for the older group are presented in Table 2.

Experimental task

The task consisted of a multiple errands task (see Logie et al., 2011). The environment within which the task was performed was the ‘Discoveries’ section of the National Museum of Scotland (Figure 1A). Prior to completing either task, participants were given a map of the ‘Discoveries’ section and told that they would only see the map once and would be allowed to study it for one minute. The map showed five exhibits which participants had to visit in the indicated order (Figure 1B). They were given a card and told that their task was to visit the five exhibits denoted on the map in the order given and write the birth or death year of the person associated with each exhibit on the card. Birth and death years were counterbalanced across both participants and tasks. In the virtual task, the years were different from the real dates to avoid learning effects. The start position for both the real and virtual reality tasks was the same (red dot on Figure 1B).

Real task

For safety reasons, participants were told that the real task would not be timed. However, the researcher stayed at the start position and recorded the path travelled by each participant on a blank map (Figure 1C left panel). The task ended when the participant returned to the researcher (red dot on Figure 1B).

Virtual reality task

The task was viewed on a 42-cm colour monitor on a Dell desktop with Intel Core Duo processor. The environment was created using the Hammer environment editor, supplied as a software development kit, to construct a 3-D model of the ‘Discoveries’ section. Figure 1A shows a screen shot of one view of the room and Figure 1B shows the layout of the room. Participants explored the virtual environment using a joystick. Participant movement within the virtual room was automatically recorded at 10 Hz, represented as a series of x,y,z coordinates, with actions recorded and time stamped. Figure 1C (right panel) shows a reconstructed route taken within the virtual room.

Procedure

The task was performed twice, once in the real environment at the National Museum of Scotland and once in the virtual environment at a testing lab of the Psychology department (Figure 1A right panel). Both tasks were performed on the same day in the span of approximately one hour. The order of the tasks (virtual-first or real-first) was counterbalanced for each age group.

Prior to completing the virtual task, participants were instructed on how to use the joystick and allowed to practice navigating through the VE. The practice VE was an empty room with various buttons placed on the walls and columns. The practice ended once five of the buttons were pressed using the trigger on the joystick. Participants were allowed to practice until they felt comfortable navigating through the practice VE. The VE was a replica of the 'Discoveries' section of the National Museum of Scotland (Figure 1A right panel), complete with each exhibit and a plaque providing the name and dates of the person associated with each exhibit. Additionally, next to each plaque, there was a button that participants were instructed to press at each exhibit they visited using the trigger on the joystick. The buttons were included to record the order in which participants visited the exhibits. The program ended once five buttons were pressed.

[Insert Figure 1 near here]

Measurements

Accuracy and distance travelled were measured for both tasks. Accuracy was defined as the proportion of correct dates written on the card in the required order (range=0-1). The VR software measured distance travelled in the virtual task (Figure 1C right panel). In the real task, the researcher traced the path travelled by each participant on a blank map (Figure 1C left panel). This path was then digitalized and the Euclidean distance was calculated using a MATLAB script developed for this analysis. For comparison purposes, the real and virtual distances were rescaled to a 50x50 room.

Analysis

There were four parts to the analysis. First, t-tests were used to determine if there were age differences on any of the experimental variables (virtual accuracy, real accuracy, virtual distance, and real distance). Additionally, t-tests were used to determine if accuracy and distance travelled were different between the virtual and real tasks for both age groups separately. Second, stepwise multiple regression analyses were performed to determine which variables predict accuracy and distance travelled in the virtual and real tasks for each age group. All predictor variables were centred prior to analysis. The order that the tasks were performed was included as an additional predictor variable to determine if the first environment in which the task was completed influenced performance. The Akaike information criterion (AIC) was used for model comparisons (Akaike, 1998). Third, when a predictor was found to be significant for both older and younger adults, further analyses were performed to determine if the regression coefficients were significantly different between the two age groups. Fourth, to determine whether performance in this task was sensitive to cognitive ageing, the age-specific variables (ACE-III scores and DLF total %) were added in a stepwise manner to the multiple regressions for the older group. Post hoc power analyses were performed using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009) for each multiple regression equation. The results of these analyses are presented in Supplementary Material 3. We calculated the effect size corresponding to the outcomes from such analysis (Rosenthal, 1994). To interpret such outcomes, we relied on the relationship between Cohen-*d* and R^2 (Small effect d=0.2, R^2=0.01; Medium effect d=0.5, R^2=0.059; Large effect d=0.8, R^2=0.138).

Results

Two older and five younger participants provided incomplete data due to technical problems performing the virtual task (i.e., handling the joystick, which prevented recording their distance data). However, these participants could still navigate around the VE and write the year on the card, so for these seven participants the virtual distance is missing in the analyses but their virtual accuracy scores were included. Additionally, one older and one younger participant were outliers (z-score > +/-2) for their age group on virtual distance. For this reason all virtual task data (distance and accuracy) for these participants was excluded from the analyses. The final data comprised of 21 older and 22 younger participants.

The IT questionnaire revealed some significant differences between the age groups (Table 3). Overall, participants in the older group had used the various devices for significantly longer than participants in the younger group; however, the younger group had significantly more experience using these devices than the older group. Specifically, older adults had significantly more experience using computers and had spent more time using computers and tablets than younger adults. Younger adults had significantly more experience using smartphones than older adults. Despite these time and experience age differences, there were no significant age differences for any of the ratios. Hence, the older and younger groups were matched for their overall familiarity with technology. Importantly, there were no significant differences for any of the gaming console measures between the older and younger groups, which has been shown to aid navigation in VEs, especially in older adults (Anguera et al., 2013).

[Insert Table 2 about here]

[Insert Table 3 about here]

For each age group, there were no significant differences in age, education, ACE-III scores, or DLF percentages between task orders ($p>0.05$). Mean accuracy and distance data is presented in Table 4.

Group comparisons

There were no significant differences in virtual accuracy, real accuracy, virtual distance, or real distance between younger and older adults. Accuracy was not significantly different between the virtual and real tasks for both older and younger adults; however, both older and younger adults travelled significantly longer distances in the real task than in the virtual task. These results could not be accounted for by limited power (see Supplementary Material 3).

Regression models

The second, third, and fourth parts of our analysis used multiple regressions to identify specific variables that predict task performance. By examining the patterns, or in some cases lack of any discernible pattern, created by these predictive variables in relation to task environment and/or age, we can then make inferences about whether the cognitive processes required to complete this task are consistent or vary across task environment and age. The results of all regression models are summarized in Figure 2 and Supplementary Material 4.

[Insert Figure 2 about here]

Younger adults. The models for predicting younger adults' performance are summarized in Figure 2A. Virtual accuracy was found to be the strongest predictor of real accuracy and vice versa (both explaining 73.19% of the variance and denoting a large effect size). While task order only explained 20.51% of the variance in real distance (where performing the virtual task first resulted in travelling longer distances in the real task) this still corresponds to a large effect size (Rosenthal, 1994). Interestingly, we found that the one-way interaction between virtual accuracy and task order predicted virtual distance. When younger participants performed the real task first, there was a stronger relationship between virtual accuracy and virtual distance (i.e. improvements in accuracy are more greatly related to better spatial memory/virtual distance). When the virtual task was performed first, the predictive value of virtual accuracy on virtual distance was not as strong (Figure 3). This model explained 71.35% of the variance in virtual distance which corresponds to large effect sizes (Rosenthal, 1994).

[Insert Figure 3 about here]

Older adults. The models for predicting older adults' performance are summarized in Figure 2B. Again, the amount of variance explained by these models (R^2) corresponds to large effect sizes (Rosenthal, 1994). Similar to the models for younger adults, virtual accuracy was the strongest predictor of real accuracy and vice versa. Further analyses determined that the virtual accuracy regression coefficient was the same for both older and younger adults ($p=0.106$). That is, increases in virtual accuracy result in the same increases in real accuracy for both age groups. However, these same analyses determined that the real accuracy regression coefficient in younger adults was significantly larger than the regression coefficient in older adults ($p<0.01$). This means that for both age groups, increases in virtual task accuracy were associated with an increase in real task accuracy but that association was stronger for younger participants. Additionally, the best models for virtual accuracy and real accuracy also included the statistically insignificant contribution of virtual distance. The proportion of variance (R^2) accounted for by the two-factor model including virtual distance in older adults was slightly larger than that accounted for by the one-factor model in younger adults (77.72% vs. 73.19% for virtual accuracy and 75.07% vs. 73.19% for real accuracy).

Just like in younger adults, the best predictor of real distance in older adults was task order, where performing the virtual task first resulted in travelling longer distances in the real task. Further analyses determined that the magnitude of the effect of task order on real distance was the same for both age groups ($p=0.779$). For older adults, the best predictor model also included insignificant contributions of virtual accuracy and virtual distance. This three-factor model for older adults accounted for a much larger proportion of variance (58.92%) than the one-factor model for younger adults (20.51%) (models achieved large effect sizes). Older adults were most different from younger adults in virtual distance, where the only predictor was found to be real distance (explained 22.57% of the variance denoting a large effect size).

Older adults with age-specific variables. The regression models for older adults with the addition of age-specific variables are summarized in Figure 2C. Visuospatial abilities, as measured by ACE-III visuospatial scores, were found to be a significant predictor for both virtual and real accuracy in older adults. The addition of visuospatial abilities to the regression model predicting virtual accuracy, increased the amount of variance explained from 77.72% to 85.58%. For the regression model predicting real accuracy, the addition of visuospatial abilities increased the amount of variance explained from 75.07% to 86.05%.

Daily living functionality, as measured by the DLF percentage, was found to be a significant predictor of both virtual and real distance in older adults. With the addition of daily living functionality to the regression model for virtual distance, the amount of variance explained more than doubles from 22.57% to 50.58%. For the regression model predicting real distance, with the addition of the DLF percentage, the contribution of virtual accuracy became insignificant. This suggests that the predictive effect of accuracy is driven by the abilities these participants have to function at this particular age, and that these abilities are effectively captured by the Functions of Everyday Life questionnaire. A regression model with task order, virtual distance, and DLF percentage was best at predicting real distance in older adults. The amount of variance explained increased from 58.92% to 67.61%.

Discussion

The principal aim of this study was to compare performance of a multiple errands task between different testing environments and across age. Furthermore, we aimed to identify specific variables that can predict such performance and determine if these variables change with age. There were five key findings of this study: (1) testing environment has a significant effect on how efficiently, but not how accurately, individuals performed the task; (2) there is a task order effect that determines how efficient individuals are at performing the task in the real world; (3) older adults can perform this task with the same accuracy and efficiency of younger adults but need to access more cognitive resources to do this; (4) older adults struggle more in unfamiliar (e.g., virtual) environments; and (5), there is evidence of knowledge transfer between real and virtual environments in younger adults.

The first two findings mentioned above are particularly important because they are true regardless of age. We first identified a dissociative effect of testing environment on performance. Even though mean accuracy in the virtual and real tasks was the same, participants of all ages were less efficient (i.e., travelled longer distances) in the real task compared to the virtual task. This result differs from previous studies that have reported worse performance in VR tasks compared to real world performance (Allain et al., 2014; Cushman et al., 2008). A number of factors might account for such discrepancies. A difference between these earlier studies and the current study is the nature of the VEs used. In our study we asked participants to perform a task within an environment that provided familiarity cues, e.g., the Museum of Scotland is one of the most visited attractions in town. Such clues might have distracted participants and led them to wander more within such an environment. These factors may have had a greater impact on this study as participants performed the task in such environments only once (see for example Waller, Hunt, & Knapp, 1998). Another potential influence on performance could be the three-dimensional properties of real and virtual environments. Lazaridou and Psarra (2017) suggested that in greater radial distributions (i.e., as in real sensory richer spaces), people are more attracted by the adjacent location and also more likely to spend time browsing panoramic views. This could explain why they navigate more in real than in virtual spaces. In our task the virtual testing room was isolated from the other rooms (i.e., exits were not available) seemingly reducing the radial distribution of such an environment. Moreover, as in Lazaridou and Psarra (2017), our virtual environment did not present other people sharing the same space. Having other people also present in the real environment might have provided further distracting cues rendering spatial navigation more challenging. Nevertheless, we did not find such environmental factors to be selectively detrimental for healthy older people navigational abilities, thus reinforcing the validity of this context to investigate functional capacity or lack thereof in old age. The evidence presented here reinforces the need to consider meaningfulness of customized environments when developing rehabilitation programs aimed at enhancing cognitive abilities. We will come back to this issue later.

The second age-independent finding of this study was that there was a task-order effect for how efficient people are at performing this task in the real world. People who performed the real task first are better than people who performed the virtual task first, indicating that initial exposure to natural environments promotes cognitive performance whereas initial exposure to artificial environments hinders such performance. It is worth noting that in the present study there was a one-off exposure to the task, which may have posed challenges when participants attempted to rely on the experience drawn from the virtual task to perform the real task. A single exposure may not be enough to promote information transfer between virtual and real environments. For example, Waller et al. (1998) found that training consisting of short exposures to a virtual environment were not more effective than training with a map in promoting real task performance. However, when enough time was spent during the virtual environment training, performance on a task requiring route knowledge surpassed that of map training and was indistinguishable from training in the real world. An alternative explanation could be that in our study before beginning the first task all participants were initially introduced to the space by studying a two-dimensional map. Previous research has shown that map learning results in orientation-specific mental representations (Cutmore et al., 2000; Richardson et al., 1999; Thorndyke, 1981; Thorndyke & Hayes-Roth, 1982). Even though we attempted to make the virtual environment as similar to the real world as possible, it may have had missing essential orientation cues that would help participants pair the virtual environment with the mental representation they had created previously. If these orientation cues were not present, it could have caused participants to feel uncertainty about the accuracy of their mental representation and this uncertainty affected these participants' ability to navigate when they subsequently performed the real task. Future studies should investigate the amount of exposure needed to promote knowledge transfer across virtual and real environments and ways of enhancing the effectiveness of spatial cues during the instruction stage of multiple errands tasks to be performed in VEs.

The third main finding of this study is related to the specific differences between older and younger adults on this task. Despite performing at the same level as younger adults, more variables in our multiple regression analyses predicted performance for older adults.

These differences suggest that healthy older adults relied on more resources to achieve levels of performance similar to those shown by younger adults. Taking into account the abundance of previous research documenting age-related cognitive decline in healthy older adults, we can conclude that the older participants in this study needed to access more resources to compensate for such decline while they completed the task (Park, O'Connell, & Thomson, 2003). Similar suggestions have been made by other authors (Grady et al., 2003). The fact that these compensatory mechanisms, which have led to the proposal of the Scaffolding Theory of Ageing and Cognition (Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Park, 2014), also support performance in more ecologically valid settings such as those used in the present study is a promising finding supporting the feasibility of VR technologies for cognitive assessment and intervention.

This suggestion is underscored by our findings that, for older adults, visuospatial ability had an effect on task accuracy and daily living function had an effect on task efficiency. The mere fact that we were able to identify a measureable and predictive influence of visuospatial abilities and daily living functions on this task is particularly noteworthy because both have been well documented to gradually decline in normal aging (Klencklen et al., 2012; Millán-Calenti et al.; Moffat, 2009; Zancada-Menendez et al., 2015). This suggests that, even for healthy individuals, age-related decline in these areas greatly effects how they perform tasks in either real or virtual environments. Even though we did not have analogous measurements of visuospatial ability and daily living function for younger adults, it is extremely unlikely that the inclusion of such variables would have had any significant contribution to the task performance of younger adults because, in the absence of neuropsychiatric disorders or pathology, younger adults do not experience any difficulties with navigation or completing everyday tasks. Additionally, because all older participants were screened for any cognitive dysfunction, we can conclude that the VR task used in this study is informative about the cognitive processes during healthy cognitive aging.

Although it is evident that visuospatial ability and daily living function have an effect on task performance, the interaction between these functions seems to be complex. In the real task, we observed the anticipated relationship: visuospatial ability and daily living function are positively related to performance. Yet in the virtual environment, the relationship is reversed and these variables are negatively related to performance. In other words, the more functional an individual is, the more capable they are in real world scenarios but less optimal in virtual scenarios. This dissociation is our fourth main finding and suggests that older adults are more comfortable in real scenarios, perhaps because they are familiar with real spaces whereas virtual spaces are unfamiliar (see comment above about meaningfulness; see also Yang et al., 2013). It is worth noting that such discrepancies cannot be accounted for by IT skills as the two groups were matched. When put into an unfamiliar environment, high functioning individuals might be more motivated to explore and create a clear mental representation of the space rather than having to worry about completing the task as efficiently as possible (see for example Hess, 1985). For this study in particular, we believe that this was entirely possible because we did not time the task, allowing them to take advantage of the rare opportunity of being immersed in a virtual environment. Our finding that the efficiency of older adults in the virtual environment, but not in the real world, predicts how accurate they are in the real task further supports this idea. Overall, in a healthy population, it appears that the functional impact of age-related cognitive decline is not as relevant on familiar as it is on unfamiliar environments.

The fifth and final main finding of this study helps answer one of the more important questions asked in VR research: whether there is knowledge transfer between real and virtual environments. Results of previous studies on this phenomenon have been mixed, with some finding evidence for knowledge transfer (Richardson et al., 1999; Stanton et al., 2002; Waller et al., 1998; Wallet et al., 201) and others finding no evidence (Koenig et al., 2011; Ruddle et al., 1997). In the current study, we only found evidence of knowledge transfer for younger adults. With regard to what influences how efficient younger adults were in the virtual task, we observed a unique interaction between task order and virtual task accuracy. Younger adults benefited in the virtual environment when they had previous knowledge of navigating through an analogous environment (i.e., performed the real task first). It is important to emphasize that knowledge transfer was only found in one direction, from real to virtual, which is consistent with some prior findings (Richardson et al., 1999). Since our previously discussed results show that older adults appear to have more difficulty than younger adults in virtual spaces, it would be interesting to see if with additional training we would also observe knowledge transfer in older adults (e.g., Waller et al., 1998).

Even though this study was informative regarding differences in performance on a multiple errands task in virtual and real scenarios and across age, it also had some limitations. First, despite closely resembling the real room at the National Museum of Scotland, there were a couple differences in the VE such as the inclusion of buttons to the VE and simplified nameplates next to each exhibit. Similar modes of collecting responses have been reported previously (Law et al., 2013; Logie et al., 2009; 2011). We suggest that future studies should aim at reducing such differences. Additionally, due to the unequal numbers of males and females, we were unable to analyse the influence of sex, which has been shown to impact navigation performance (Cutmore et al., 2000). Despite these limitations, we believe that this study represents an important step towards understanding how VR can be made an optimal tool for specific populations such as that of older adults.

As discussed in the introduction, the ecological validity of VR is one of the major concerns regarding the use of this technology. The results of this study highlight the problem with assuming that VR and real-world scenarios are interchangeable. This is especially important in terms of the potential application of VR for rehabilitation. For VR rehabilitation to be effective, individuals need to be as comfortable in virtual scenarios as they are in real scenarios. In this study, participants were only exposed to the virtual environment once, and future research must be conducted to determine the optimal training conditions in virtual scenarios that would allow individuals to reach a point of equal comfort. The impact that IT based tools can have on the assessment and intervention of frail elderly people and of those at risk of dementia has been recently highlighted (Valdes et al., 2016). The potential of VR as assessment and intervention tools for such vulnerable groups become even more apparent when factors such as the unstoppable growth of the elderly population linked to repeated failures of drug trials for dementia are brought forward.

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Table 1. Previous research using VR to investigate, assess, and rehabilitate cognitive abilities

Assess cognitive changes in Alzheimer's disease

- Allain et al., 2014
- Cushman, Stein, & Duffy, 2008
- Kessels, van Doormaal, & Janzen, 2011
- Pengas et al., 2012
- Plancher, Tirard, Gyselinck, Nicolas, & Piolino, 2012
- Widmann, Beinhoff, & Riepe, 2012

Assess cognitive changes in Mild Cognitive Impairment (MCI)

- Plancher et al., 2012
- Weniger et al., 2011

Assess cognitive changes in traumatic brain injury (TBI)

- Krch et al., 2013

Assess cognitive changes in stroke

- Josman et al., 2014

Assess knowledge transfer between real and virtual environments

- Koenig, Crucian, Dalrymple-Alford, & Dünser, 2011
- Ruddle, Payne, & Jones, 1997

Develop rehabilitation tools for cognitive or motor deficits

- Cameirao, Badia, Oller, & Verschure, 2010
- Klinger et al., 2013
- Tost et al., 2009

Assess navigation abilities

- Cushman et al., 2008
- Cutmore, Hine, Maberly, Langford, & Hawgood, 2000
- Kessels et al., 2011
- Moffat, Zonderman, & Resnick, 2001
- Richardson, Montello, & Hegarty, 1999
- Taillade et al., 2013
- Zancada-Menendez et al., 2015

Investigate everyday multitasking abilities

- Law, Trawley, Brown, Stephens, & Logie, 2013
- Logie, Trawley, & Law, 2011
- Trawley, Law, & Logie, 2011

Determine the value of VR for cognitive training

- Anguera et al., 2013
- Legault, Allard, & Faubert, 2013

Assess age-related cognitive decline

- Anguera et al., 2013
- Craik & Bialystok, 2006
- Cushman et al., 2008
- Moffat et al., 2001
- Plancher et al., 2010
- Taillade et al., 2013
- Zancada-Menendez et al., 2015

Table 2. Demographic characteristics for both age groups and ACE-III scores and DLF percentage for older group.

	Older Group				Younger Group			
	n	*Range*	*M*	*SD*	*n*	*Range*	*M*	*SD*
Gender								
Male	10	-	-	-	4	-	-	-
Female	11	-	-	-	18	-	-	-
Age	21	58-74	64.19	4.39	22	18-29	21.05	3.15
Education	20	11-26	16.35	3.44	19	12-21	15.92	2.62
ACE-III								
Total (max. 100)	21	93-100	97.19	2.09	-	-	-	-
Attention (max. 18)	21	16-18	17.48	0.75	-	-	-	-
Memory (max. 26)	21	22-26	25.19	1.08	-	-	-	-
Fluency (max. 14)	21	11-14	13.62	0.80	-	-	-	-
Language (max. 26)	21	24-26	25.33	0.80	-	-	-	-
Visuospatial (max. 16)	21	14-16	15.52	0.60	-	-	-	-
DLF percentage	21	33.33-50.98	39.53	3.31	-	-	-	-

Table 3. Summary of IT questionnaire.

	Older group (n=21)			Younger group (n=22)		
	Range	*M*	*SD*	*Range*	*M*	*SD*
Computer usage						
Years***	0-49	22.67	12.69	0-18	9.50	5.84
Experience**	12-64	40	14.75	13-42	28.95	7.35
Ratio (experience/years)	0-3	1.67	0.69	0-3.5	2.07	1.21
Tablet usage						
Years*	0-5	1.48	1.66	0-4	0.50	1.11
Experience	0-19	8.14	8.13	0-20	4.05	7.61
Ratio (experience/years)	0-15	3.49	4.22	0-40	2.98	8.85
Smartphone usage						
Years	0-10	1.39	2.61	0-6	2.49	2.27
Experience***	0-23	6.62	8.87	0-23	17.55	6.46
Ratio (experience/years)	0-29.85	2.73	6.67	0-92	10.02	20.17
Gaming console usage						
Years	0-0	0	0	0-10	0.68	2.21
Experience	0-0	0	0	0-13	1.50	3.90
Ratio (experience/years	0-0	0	0	0-5	0.44	1.26
Overall IT usage						
Years***	0-52	25.53	13.90	0-25	13.17	8.30
Experience*	8-60	32.10	17.98	20-61	42.55	11.93
Ratio (experience/years)	0-8.4	1.49	1.69	0-78	5.59	16.22

Note: Student's t-test performed between older and younger adults; $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$

Table 4. Mean accuracy and distance data broken down by age group and task order.

	Older group									Younger group								
	Virtual task first (n=11)			Real task first (n=10)			Both task orders (n=21)			Virtual task first (n=11)			Real task first (n=11)			Both task orders (n=22)		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Virtual task measures																		
Accuracy	10	0.88	0.21	10	0.98	0.06	20	0.93	0.16	10	0.76	0.42	11	0.87	0.31	21	0.82	0.36
Distance	9	22.65	13.90	9	13.20	5.44	18	17.92	11.34	9	13.47	7.64	7	10.78	3.36	16	12.29	6.13
Real task measures																		
Accuracy	11	0.76	0.27	10	0.88	0.32	21	0.82	0.29	11	0.73	0.39	11	0.76	0.34	22	0.75	0.36
Distance	11	29.06	4.69	10	19.63	5.48	21	24.57^{*}	6.92	11	28.88	9.17	11	20.67	7.74	22	24.77^{***}	9.29

Note: Student's t-tests performed between real task distance and virtual task distance; $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$

Figure Captions

Figure 1. (A) Image of real environment (the 'Discoveries' section of the National Museum of Scotland) on the left and the corresponding area in the virtual environment on the right. (B) Map and written task instructions given to participants at beginning of experiment. (C) Path travelled by participant in real task (left) and virtual task (right).

Figure 2. Summary of multiple regression analyses for (A) younger adults, (B) older adults, and (C) older adults with the addition of age-specific variables. The solid arrows represent significant predictor variables. The dashed arrows represent insignificant predictor variables. The curved line represents an interaction between predictor variables. The numbers next to the arrows is the β for each predictor variable (*$p<0.05$, **$p<0.01$, ***$p<0.001$, +approaching significance e.g., $p<0.06$).

Figure 3. Relationship between distance and accuracy in the virtual environment as a function of task order.

Figure 1.

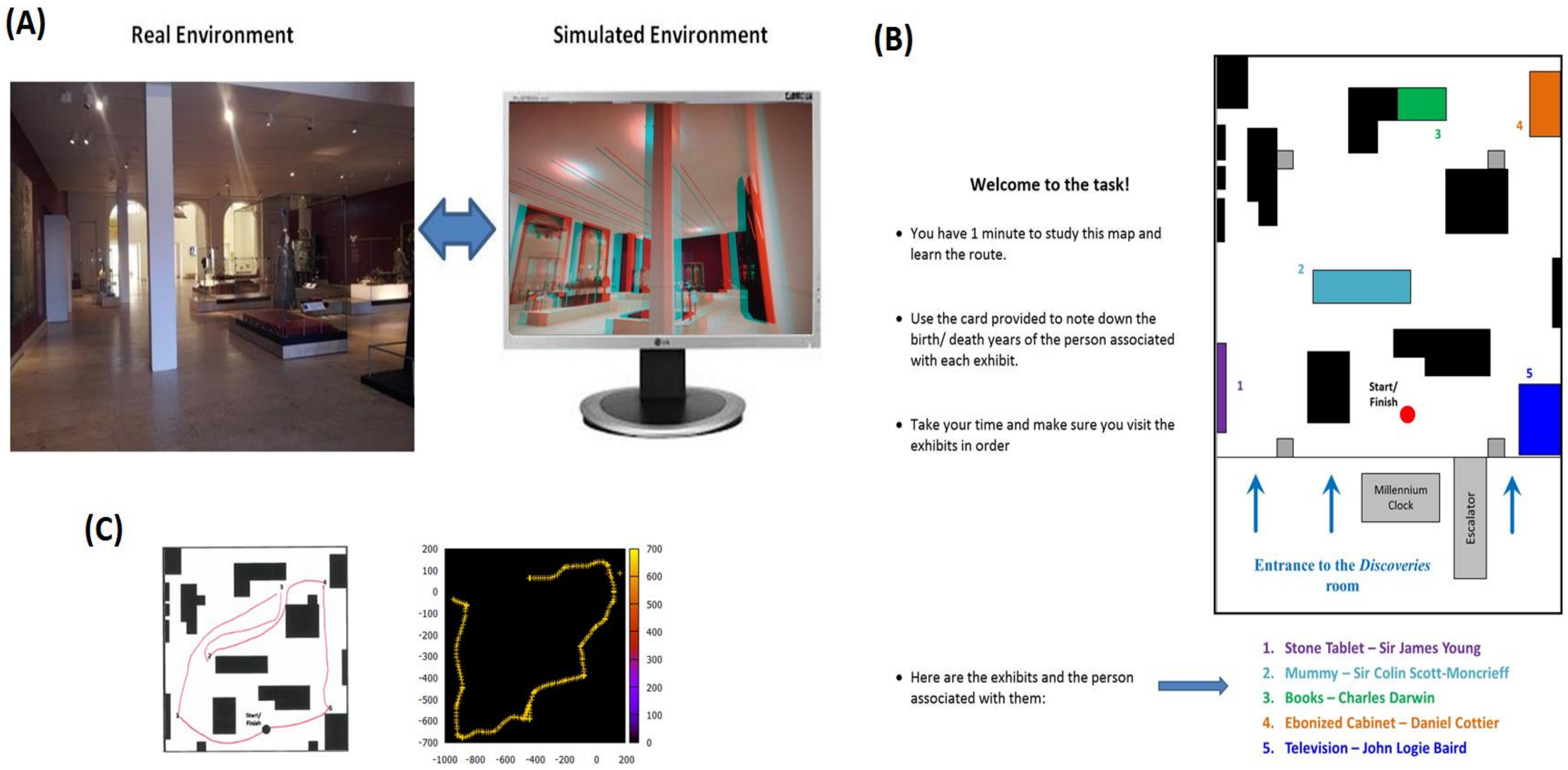

(A)
Real Environment
Simulated Environment
(B)
Welcome to the task!
You have 1 minute to study this map and learn the route.
Use the card provided to note down the birth/ death years of the person associated with each exhibit.
Take your time and make sure you visit the exhibits in order
Here are the exhibits and the person associated with them:
Start/ Finish
Millennium Clock
Escalator
Entrance to the Discoveries room
1. Stone Tablet – Sir James Young
2. Mummy – Sir Colin Scott-Moncrieff
3. Books – Charles Darwin
4. Ebonized Cabinet – Daniel Cottier
5. Television – John Logie Baird
(C)

Figure 2.

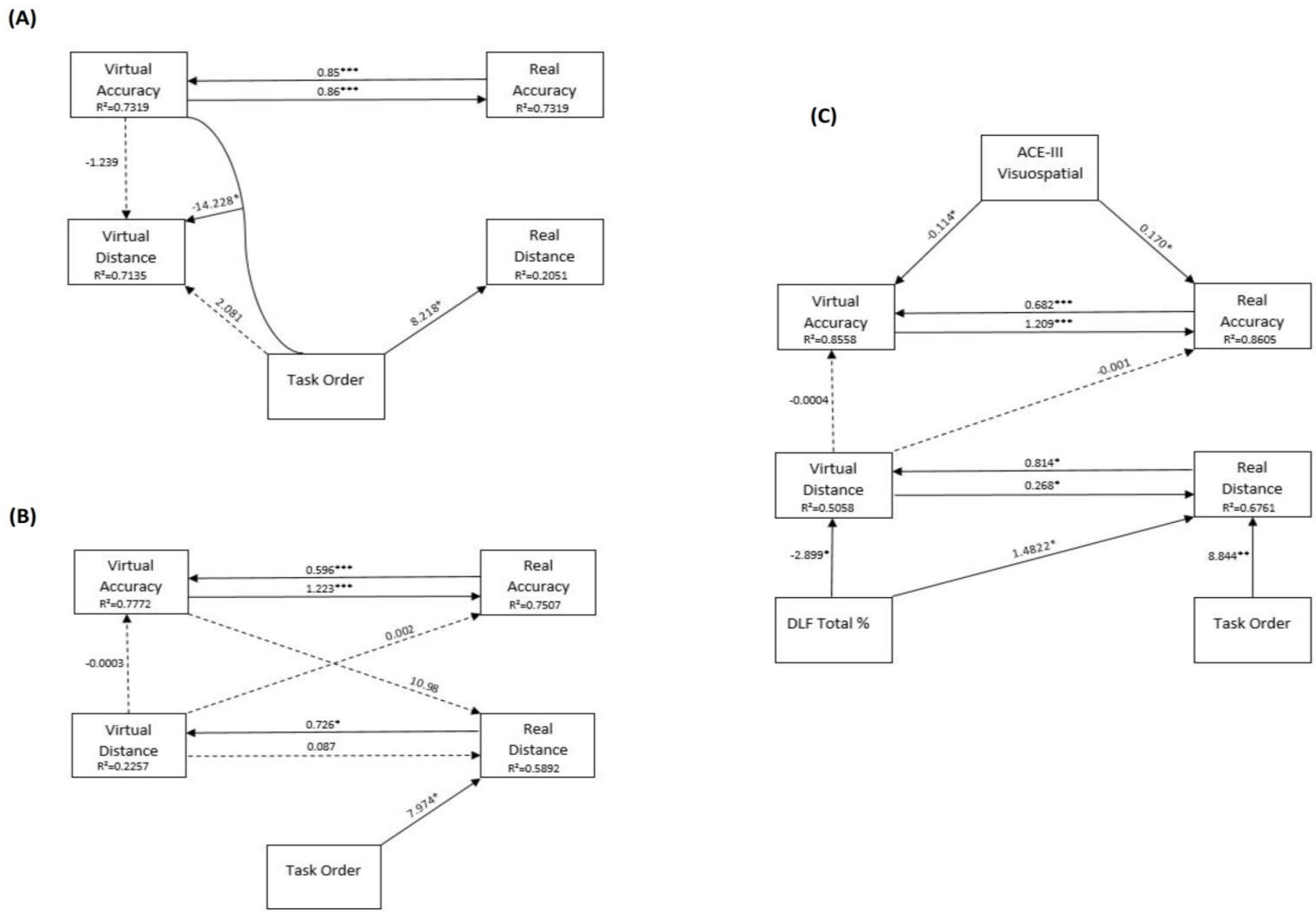
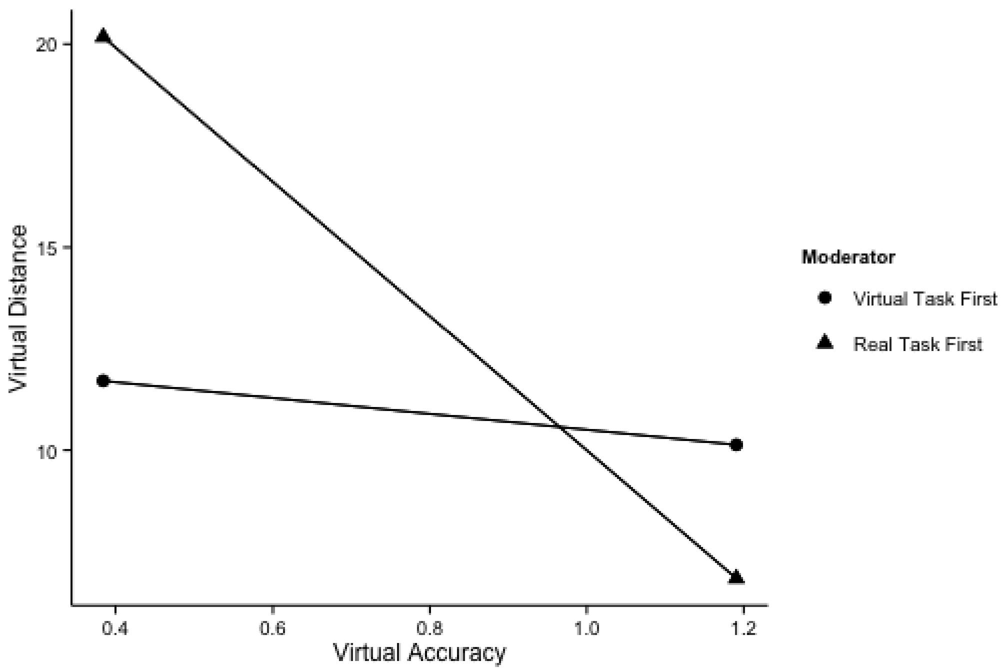

(A)
Virtual Accuracy R²=0.7319
Real Accuracy R²=0.7319
0.85***
0.86***
-1.239
-14.228*
Virtual Distance R²=0.7135
Real Distance R²=0.2051
2.081
8.218*
Task Order
(B)
Virtual Accuracy R²=0.7772
Real Accuracy R²=0.7507
0.596***
1.223***
0.002
-0.0003
10.98
Virtual Distance R²=0.2257
Real Distance R²=0.5892
0.726*
0.087
7.974*
Task Order
(C)
ACE-III Visuospatial
-0.114*
0.170*
Virtual Accuracy R²=0.8558
Real Accuracy R²=0.8605
0.682***
1.209***
-0.001
-0.0004
Virtual Distance R²=0.5058
Real Distance R²=0.6761
0.814*
0.268*
-2.899*
1.4822*
8.844**
DLF Total %
Task Order

Figure 3.


20
15
10
Virtual Distance
0.4
0.6
0.8
1.0
1.2
Virtual Accuracy
Moderator
Virtual Task First
Real Task First

Supplementary Material

Supplementary Material 1

IT Questionnaire

1. Do you use a computer? ____________________

If yes, for how long have you used a computer? ________________________________

2. Please circle the best answer describing the frequency with which you use a computer to perform the following activities.

	Not Applicable — Never — Occasionally — Frequently 0 — 1 — 2 — 3
Send/receive emails	0 — 1 — 2 — 3
Surf the internet	0 — 1 — 2 — 3
Use a word processer	0 — 1 — 2 — 3
Play games	0 — 1 — 2 — 3
Use an internet telephone (e.g. Skype)	0 — 1 — 2 — 3
Social networking (e.g. Facebook, Twitter)	0 — 1 — 2 — 3
Read e-books	0 — 1 — 2 — 3
Make phone calls	0 — 1 — 2 — 3
Send text messages	0 — 1 — 2 — 3

3. Do you use a tablet?____

If yes, for how long have you used a tablet? ___________________________________

4. Please circle the best answer describing the frequency with which you use a tablet to perform the following activities.

	Not Applicable (0) — Never (1) — Occasionally (2) — Frequently (3)
Send/receive emails	0 — 1 — 2 — 3
Surf the internet	0 — 1 — 2 — 3
Use a word processer	0 — 1 — 2 — 3
Play games	0 — 1 — 2 — 3
Use an internet telephone (e.g. Skype)	0 — 1 — 2 — 3
Social networking (e.g. Facebook, Twitter)	0 — 1 — 2 — 3
Read e-books	0 — 1 — 2 — 3
Make phone calls	0 — 1 — 2 — 3
Send text messages	0 — 1 — 2 — 3

5. Do you use a smartphone? ______________________________

If yes, for how long have you used a smartphone? ____________________

6. Please circle the best answer describing the frequency with which you use a smartphone to perform the following activities.

	Not Applicable (0) — Never (1) — Occasionally (2) — Frequently (3)
Send/receive emails	0 — 1 — 2 — 3
Surf the internet	0 — 1 — 2 — 3
Use a word processer	0 — 1 — 2 — 3
Play games	0 — 1 — 2 — 3
Use an internet telephone (e.g. Skype)	0 — 1 — 2 — 3

Social networking (e.g. Facebook, Twitter)	0—1—2—3
Read e-books	0—1—2—3
Make phone calls	0—1—2—3
Send text messages	0—1—2—3

7. Do you use a gaming console? ______________________________

If yes, for how long have you used a gaming console? ______________________

8. Please circle the best answer describing the frequency with which you use a gaming console to perform the following activities.

	Not Applicable / Never / Occasionally / Frequently 0—1—2—3
Send/receive emails	0—1—2—3
Surf the internet	0—1—2—3
Use a word processer	0—1—2—3
Play games	0—1—2—3
Use an internet telephone (e.g. Skype)	0—1—2—3
Social networking (e.g. Facebook, Twitter)	0—1—2—3
Read e-books	0—1—2—3
Make phone calls	0—1—2—3
Send text messages	0—1—2—3

Supplementary Material 2

Details of Functions of Everyday Life (DoFEL)

Version 1.0

Not Applicable — Never — Occasionally — Frequently
0—1—2—3

Name ______________________________ Subject Code__________

Date __________________

	Shopping and Money		
1	Misplaces money or forget where to find it	0—1—2—3	
2	Difficulty recognising coins or notes (bills)	0—1—2—3	
3	Difficulty handling money when paying or receiving change	0—1—2—3	
4	Difficulty recognising common products in supermarkets or shops	0—1—2—3	
5	Forgets the name of products commonly shopped for	0—1—2—3	
6	Forgets the location of products at home or in supermarkets	0—1—2—3	
7	Difficulty remembering the way to the supermarket or back home	0—1—2—3	
8	Difficulty remembering items without a shopping list	0—1—2—3	
	Total		
	Objects and People		
9	Difficulty recognising personal items (keys, clothing)	0—1—2—3	
10	Difficulty remembering the location of personal items	0—1—2—3	

11	Difficulty recognising new items (a new home appliance)		0—1—2—3	
12	Difficulty recognising familiar items (gardening tools, a book)		0—1—2—3	
13	Difficulty recognising faces of well-known people		0—1—2—3	
14	Difficulty recognising faces of people recently met		0—1—2—3	
15	Difficulty recalling the name of well-known people		0—1—2—3	
16	Difficulty recalling the name of people recently met		0—1—2—3	
17	Forgets where friends and family members live		0—1—2—3	
18	Difficulty recognising the house of old friends or family members		0—1—2—3	
19	Difficulty recognising the house of new friends		0—1—2—3	
20	Forgets where the car was parked		0—1—2—3	
21	Difficulty recognising own car (confuses it with a similar car)		0—1—2—3	
		Total		
	Technology and Communication			
22	Forgets well-known telephone numbers		0—1—2—3	
23	Forgets recently learned telephone numbers		0—1—2—3	
24	Difficulty dialling	Mobile phones	0—1—2—3	
24a		Landline phones	0—1—2—3	
25	Forgets where the landline phone is at home		0—1—2—3	
26	Forgets where the mobile phone was left		0—1—2—3	
27	Difficulty recognising own mobile phone		0—1—2—3	
28	Difficulty recognising own mobile phone’s ring tone		0—1—2—3	
29	Difficulty recalling pin codes (such as in cash machines)		0—1—2—3	

			Not Applicable (0) — Never (1) — Occasionally (2) — Frequently (3)	
30	Difficulty recognising the bank card among other cards		0—1—2—3	
31	Difficulty operating the cash machine		0—1—2—3	
32	Difficulty recalling the pin code of different bank cards		0—1—2—3	
33	Difficulty changing TV channels (operating remote controllers)		0—1—2—3	
34	Forgets the channel of commonly watched TV programs		0—1—2—3	
35	Difficulty recalling the name of TV characters		0—1—2—3	
36	Difficulty keeping track of storylines in TV programs		0—1—2—3	
37	Forgets the programs where famous TV characters act or acted		0—1—2—3	
38	Forgets the username and password of email accounts		0—1—2—3	
39	Forgets the email account provider (Hotmail, Yahoo, Gmail)		0—1—2—3	
40	Difficulty recognising or operating online communication	Emails	0—1—2—3	
		Skype	0—1—2—3	
41	Forgets how to use email (send a message, retrieve a message)		0—1—2—3	
		Total		
		Transport and Mobility		
42	Forgets basic actions when driving (how to change lights)		0—1—2—3	
43	Difficulty recognising traffic signs		0—1—2—3	
44	Difficulty driving in familiar places		0—1—2—3	

45	Difficulty driving in new places	0—1—2—3	
46	Difficulty using landmarks for directions when driving	0—1—2—3	
47	Difficulty using landmarks when walking to familiar places	0—1—2—3	
48	Difficulty using landmarks when walking to unfamiliar places	0—1—2—3	
	Total		
	Domestic Chores		
49	Difficulty operating well-known/previously used electric appliances	0—1—2—3	
50	Forgets the function of well-known/previously used electric appliances	0—1—2—3	
51	Forgets the location of electric appliances at home	0—1—2—3	
52	Forgets where to find ingredients when cooking	0—1—2—3	
53	Difficulty selecting ingredients when cooking	0—1—2—3	
54	Mixes up ingredients from different recipes	0—1—2—3	
55	Use the wrong kitchen utensils when cooking	0—1—2—3	
56	Forgets the name of ingredients when cooking	0—1—2—3	
57	Difficulty adding the correct amount of ingredients to the food	0—1—2—3	
	Total		
	Work and Social Life		
		Not Applicable 0 — Never 1 — Occasionally 2 — Frequently 3	
58	Forgets the name of people at work	0—1—2—3	
59	Forgets the date and time of tasks at work	0—1—2—3	

60	Difficulty remembering things that happened at work	0—1—2—3	
61	Difficulty allocating priority to tasks and remembering priorities	0—1—2—3	
62	Inappropriately dressed and groomed to go to work and social meetings	0—1—2—3	
63	Forgets daily work routines	0—1—2—3	
64	Difficulty recognising friends with whom interacts regularly	0—1—2—3	
65	Forgets the name of new colleagues or friends	0—1—2—3	
66	Forgets good manners during social interactions (thanking, greeting)	0—1—2—3	
67	Shows occasional inappropriate behaviours (say or does rude things)	0—1—2—3	
68	Difficulty distinguishing between social and work affairs	0—1—2—3	
	Total		
	Health and Life Style		
	Forgets to take medication in time	0—1—2—3	
70	Forgets who prescribed the medication	0—1—2—3	
71	Difficulty recognising the medication (what the red pill is for)	0—1—2—3	
72	Forgets where medicines are kept	0—1—2—3	
73	Difficulty recognising unhealthy food which was previously avoided	0—1—2—3	
74	Difficulty recognising changes in own physical status (weight, energy)	0—1—2—3	
75	Difficulty recognising healthy food which was previously preferred	0—1—2—3	
76	Forgets what activities are healthy (exercise, reading, leisure)	0—1—2—3	
77	Forgets where to practice healthy activities (gym, park)	0—1—2—3	
78	Forgets with whom to practice healthy activities	0—1—2—3	
79	Forgets regular past-time activities (walks, reading)	0—1—2—3	

80	Withdrawn from habitual leisure	0—1—2—3	
81	Forgets where to practice leisure activities (community centre)	0—1—2—3	
82	Forgets how to practice leisure activities (play bingo, cards)	0—1—2—3	
	Total		
	Grand Total		

Supplementary Material 3

Power Calculation

Abbreviations: VA: Virtual Accuracy; RA: Real Accuracy, VD: Virtual Distance, RD: Real Distance, VF: Virtual First; ACE: Addenbrooke's Cognitive Examination-revised; DFL: Daily Living Function

Older group										
Outcome Variable	*Predictor Variables*	*β*	*95% CI*	*F-Statistic*	R^2	*Power*	*Cohen's f2*	*Adj.* R^2	*Adj. Power*	*Adj. Cohen's f2*
VA	RA	0.596***	[0.396, 0.796]	F(2,15)=26.16***	0.7772	1	3.49	0.7475	0.99	2.96
	VD	-0.0003	[-0.007, 0.001]			0.99			0.99	
RA	VA	1.223***	[0.814, 1.633]	F(2,15)=22.58***	0.7507	0.99	3.01	0.7174	0.99	2.54
	VD	0.002	[-0.004, 0.008]			0.99			0.99	
VD	RD	0.726*	[0.013, 1.439]	F(1,16)=4.663*	0.2257	0.65	0.29	0.1773	0.52	0.22
						0.58			0.46	
RD	Order (VF)	7.974*	[1.87, 14.077]	F(3,14)=6.694**	0.5892	0.99	1.43	0.5012	0.94	1.01
	VA	10.98	[-29.58, 7.621]			0.97			0.89	
	VD	0.087	[-0.191, 0.366]							
Older group with age-specific variables										
Outcome Variable	*Predictor Variables*	*β*	*95% CI*	*F-Statistic*	R^2	*Power*	*Cohen's f2*	*Adj.* R^2	*Adj. Power*	*Cohen's f2*
VA	RA	0.682***	[0.502, 0.862]	F(3,14)=27.69***	0.8558	1	5.93	0.8249	1	4.71
	VD	-0.0004	[-0.004, 0.003]			1			0.99	
	ACE Vis.	-0.114*	[-0.203, -0.025]							
RA	VA	1.209***	[0.889, 1.529]	F(3,14)=28.79***	0.8605	1	6.17	0.8306	1	4.90
	VD	-0.001	[-0.006, 0.004]			1			1	
	ACE Vis.	0.170**	[0.060, 0.279]							
VD	RD	0.814*	[0.219, 1.408]	F(2,15)=7.677**	0.5058	0.97	1.02	0.4399	0.93	0.79
	DFL%	-2.899*	[-5.017, -0.78]			0.94			0.87	
RD	Order (VF)	8.844**	[3.638, 14.051]	F(3,14)=9.743***	0.6761	0.99	2.09	0.6067	0.99	1.54
	VD	0.268*	[0.004, 0.532]			0.99			0.98	
	DFL%	1.4822*	[0.161, 2.803]							
Younger group										

Outcome Variable	*Predictor Variables*	*β*	*95% CI*	*F-Statistic*	R^2	*Power*	*Cohen's f2*	*Adj.* R^2	*Adj. Power*	*Cohen's f2*
VA	RA	0.85^{***}	[0.603, 1.097]	$F(1,19)=51.87^{***}$	0.7319	1	2.73	0.7178	0.99	2.54
						0.99			0.99	
RA	VA	0.86^{***}	[0.611 1.111]	$F(1,19)=51.87^{***}$	0.7319	1	2.73	0.7178	0.99	2.54
						0.99			0.99	
VD	Order (VF)	2.081	[-1.959, 6.121]	$F(3,12)=9.96^{**}$	0.7135	0.99	2.49	0.6418	0.99	1.79
	VA	-1.239	[-9.759, 7.282]			0.997			0.977	
	Order xVA	-14.228^{*}	[-24.89, -3.567]							
RD	Order (VF)	8.218^{*}	[0.672, 15.765]	$F(1,20)=5.161^{*}$	0.2051	0.62	0.26	0.1654	0.51	0.20

Note: $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$, $^{+}$*approaching significance* ($p<0.06$)

Power analysis was carried out with the final sample size. From these calculations, it seems that there are only 2 places from our original analyses where we have may have had insufficient power: virtual distance for older adults and real distance for younger adults. However, when we add in the age-specific variables for older adults the virtual distance equation has great power. Moreover, distance was an important predictor particularly for the older group. These results suggest that power limitations would not be the reason for the null findings reported in this study.

Supplementary Material 4

Multiple regression results for each outcome variable in younger group, older group, and older group with age-specific variables.

	Older group				Younger group			
Outcome Variable	*Predictor Variables*	β	*F-Statistic*	R^2	*Predictor Variables*	β	*F-Statistic*	R^2
Virtual accuracy	Real accuracy	0.596^{***}	$F(2,15)=26.16^{***}$	0.7772	Real accuracy	0.85^{***}	$F(1,19)=51.87^{***}$	0.7319
	Virtual distance	-0.0003						
Real accuracy	Virtual accuracy	1.223^{***}	$F(2,15)=22.58^{***}$	0.7507	Virtual accuracy	0.86^{***}	$F(1,19)=51.87^{***}$	0.7319
	Virtual distance	0.002						
Virtual distance	Real distance	0.726^{*}	$F(1,16)=4.663^{*}$	0.2257	Task order (virtual first)	2.081	$F(3,12)=9.96^{**}$	0.7135
					Virtual accuracy	-1.239		
					Task order x virtual accuracy interaction	-14.228^{*}		
Real distance	Task order (virtual first)	7.974^{*}	$F(3,14)=6.694^{**}$	0.5892	Task order (virtual first)	8.218^{*}	$F(1,20)=5.161^{*}$	0.2051
	Virtual accuracy	10.98						
	Virtual distance	0.087						

	Older group with age-specific variables			
Outcome Variable	*Predictor Variables*	β	*F-Statistic*	R^2
Virtual accuracy	Real accuracy	0.682^{***}	$F(3,14)=27.69^{***}$	0.8558
	Virtual distance	-0.0004		
	ACE-III visuospatial	-0.114^{*}		
Real accuracy	Virtual accuracy	1.209^{***}	$F(3,14)=28.79^{***}$	0.8605
	Virtual distance	-0.001		
	ACE-III visuospatial	0.170^{**}		
Virtual distance	Real distance	0.814^{*}	$F(2,15)=7.677^{**}$	0.5058
	DLF total %	-2.899^{*}		
Real distance	Task order (virtual first)	8.844^{**}	$F(3,14)=9.743^{***}$	0.6761
	Virtual distance	0.268^{*}		
	DLF total %	1.4822^{*}		

Note: $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$, $^{+}$*approaching significance* ($p<0.06$)