Acceptance and usability of immersive virtual reality in older adults with objective and subjective cognitive decline

Sara Arlati[1,2*], Simona Gabriella Di Santo[3,4], Flaminia Franchini[3,4], Marta Mondellini[1], Beatrice Filiputti[3], Matilde Luchi[3], Federica Ratto[3], Giancarlo Ferrigno[2], Marco Sacco[1], Luca Greci[5]

[1] *Istituto di Sistemi e Tecnologie Industriali Intelligenti per il Manifatturiero Avanzato, Consiglio Nazionale delle Ricerche, via G. Previati 1/E, 23900 Lecco, Italy*

[2] *Dipartimento di Elettronica, Informatica e Bioingegneria, Politecnico di Milano, via G. Ponzio 34, 20133 Milano, Italy*

[3] *Laboratorio-servizio di Epidemiologia e Ricerca Clinica, IRCCS Fondazione Santa Lucia, via Ardeatina 306/354, 00142 Roma, Italy*

[4] *Dipartimento di Medicina dei Sistemi, Università degli Studi di Roma 'Tor Vergata', Facoltà di Medicina e Chirurgia - Via Montpellier, 1 - 00133 Roma, Italy*

[5] *Istituto di Sistemi e Tecnologie Industriali Intelligenti per il Manifatturiero Avanzato, Consiglio Nazionale delle Ricerche, via A. Corti 12, 20133 Milano, Italy*

[*]Corresponding author:
Sara Arlati,
Istituto di Sistemi e Tecnologie Industriali Intelligenti per il Manifatturiero Avanzato,
Consiglio Nazionale delle Ricerche,
via G. Previati 1/E,
23900 Lecco,
Italy

Dipartimento di Elettronica, Informatica e Bioingegneria,
Politecnico di Milano,
via G. Ponzio 34,
20133 Milano,
Italy

tel: +39.0341.2350202
e-mail: sara.arlati@stiima.cnr.it

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Conflict of interests
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Abstract

BACKGROUND: Virtual reality (VR) has recently emerged as a promising means for the administration of cognitive training of seniors at risk of dementia. Immersive VR could result in increased engagement and performances, however its acceptance in older adults with cognitive deficits still has to be assessed.

OBJECTIVE: To assess acceptance and usability of an immersive VR environment requiring real walking and active participants' interaction.

METHODS: 58 seniors with Mild Cognitive Impairment (MCI, n=24) or Subjective Cognitive Decline (SCD, n=31) performed a shopping task in a virtual supermarket displayed through a head-mounted display. Subjective and objective outcomes were evaluated.

RESULTS: Immersive VR was well-accepted by all but one participant (TAM3 positive subscales >5.33), irrespective of the extent of cognitive decline. Participants enjoyed the experience (spatial presence 3.51 ± 0.50, engagement 3.85 ± 0.68, naturalness 3.85 ± 0.82) and reported negligible side-effects (SSQ: 3.74; q1-q3: 0-16.83). The environment was considered extremely realistic, such as to induce potentially harmful behaviors: one participant fell while trying to lean on a virtual shelf. Older participants needed more time to conclude trials. Participants with MCI committed more errors in grocery items' selection, and experienced less "perceived control" over the environment.

CONCLUSION: Immersive VR was acceptable and enjoyable for older adults in both groups. Cognitive deficits could induce risky behaviours, and cause issues in the interactions with virtual items. Further studies are needed to confirm acceptance of immersive VR in individuals at risk of dementia, and to extend the results to people with more severe symptoms.

Keywords: mild cognitive impairment, subjective cognitive decline, immersive virtual reality, acceptance, usability, cybersickness.

Introduction

Age-related cognitive impairment represents one of the major health challenges of our time. Dementia is a progressive disorder causing the deterioration of mental functioning, thus gradually leading to the loss of autonomy in the activities of daily living [1]. Its onset – i.e. the early neuropathological manifestations – may precede by many years the occurrence of the first clinical symptoms [2,3]. This could partially explain why, so far, clinical trials have not identified an effective, disease-modifying treatment for Alzheimer's Disease (AD) and other dementias [4].

Since both a preclinic and prodromic phase have been identified for all dementia types [5], the attention has progressively shifted onto people with Subjective Cognitive Decline (SCD) [6] and Mild Cognitive Impairment (MCI) [7] as possible candidates for pharmacological or non-pharmacological strategies aimed to prevent or postpone the onset of dementia [8].

MCI is a syndrome occurring when cognitive decline is greater than what expected for an individual's age and education level, but that does not interfere significantly with activities of daily living [9]. People with MCI have an increased risk of developing dementia, even if a consistent percentage remain stable or reverse to normality during the years [10]. Also people with SCD are at increased risk of developing dementia, compared to people without a subjective perception of cognitive decline [11]. Thus, they could represent an optimal target population for preventing programs [12].

Though their effectiveness in preventing cognitive decline has still to be definitively proven, promising results seem to derive from non-pharmacological interventions based on cognitive interventions, physical exercise, and/or treatment of lifestyle-related diseases [13].

Regarding cognitive interventions and cognitive training (CT) there is a trend away from paper and pencil based training to Computerized Computer Training and Virtual Reality (VR)-based training programs, which can both implement tailored interventions by adapting the level of difficulty and the kind of tasks depending on the cognitive profile of each single user [14–16].

With regard to VR, it has been argued that the experienced Sense of Presence (SoP, i.e., the feeling of 'being there' in a computer-generated scenario) may influence both the motivation to train and the treatment effectiveness [17,18]. Currently, Head Mounted Displays (HMDs) are considered the VR devices able to convey the highest levels of immersion, and thus of SoP [19]. However, their widespread use in healthcare is hindered by the risk of experiencing cyber-sickness, the need of ensuring users' safety, and users' negative attitude [20,21].

Because of these reasons, it is essential to assess whether immersive VR applications are acceptable by potential target subjects prior to their administration. This assessment is of particular importance when dealing with vulnerable populations, as in the case of older adults with cognitive decline, who might have an even increased resistance toward the use of new technologies [22,23].

Preliminary evidence indicates that older adults could enjoy the experience with VR technologies [23], and that they are not highly sensitive to cyber-sickness [24], possibly because susceptibility to side-effects appears to decrease with age too [25].

Previous outcomes also demonstrated that the advent of high-quality HMDs had constituted a key step for implementing new interventions exploiting such a technology; with novel devices, in fact, side-effects may be strongly limited, while SoP could reach very high levels according to an inverse correlation pattern [20,21].

In spite of this evidence, the majority of the studies that exploited a HMD for the assessment or the treatment of MCI either foresaw that the participant was static [26,27], or used a navigation metaphor (e.g. a remote or a joystick [28,29], a wheelchair [30], or head-tilting [31]). This may represent an issue, as not being able to navigate freely in the environment, or to manipulate objects, could seriously affect users' control over the scene, and culminate in frustration or annoyance, thus limiting SoP [32,33], and consequently the motivation to adhere to the rehabilitative program [34].

Vice versa, natural navigation paradigms (i.e., walking) can contribute to increase user's SoP and reduce the potential occurrence of cyber-sickness due to vection [21]. This may also increase the risk of falling, as postural sway increases during the exposure to an immersive VR environment [35]; however, first experiences were positive, and no adverse event was reported [36,37].

With regard to existing evidence, it has also to be mentioned that only a few studies have explicitly evaluated the acceptance and the usability of HMD-based VR in older people [23,37,38] and in seniors with MCI using standardized measures [39]. Nonetheless, they all recorded positive attitudes, thus indicating that immersive VR, differently from other technologies, may be well accepted by older adults, possibly because of the increased SoP, the innovativeness of the means, or its higher ecological validity.

Given these premises, we proposed a study aimed at assessing whether an interactive immersive VR application dedicated to CT, which emulates shopping at the supermarket and requires the user to walk around, was usable and acceptable in a sample of elderly participants with MCI or SCD. In this research, the interaction with the virtual environment was more dynamic and ecological than previous studies, as the participants performed the proposed exercises walking and moving within the virtual environment, as if they were really in a supermarket aisle.

The virtual environment that was used in this study was first tested in a sample of healthy young adults, with positive outcomes [40]. Its features respond to the requirements of an application that should not cause the occurrence of malaise [41], since the navigation occurs naturally by walking and the user has easy and complete control over the scene. The limited exposure time (e.g., 15 minutes) should also limit the potential occurrence of balance issues, therefore ensuring the safety of participants.

We thus hypothesized that the 'Virtual Supermarket' would be acceptable and enjoyable for older adults with objective and subjective cognitive decline; we expected low scores of cyber-sickness and good Sense of Presence (SoP) for all participants, irrespectively to their personal characteristics. We also expected a good acceptance of technology, mediated by the engagement elicited by the application. Finally, we also hypothesized that participants' age, education and global cognitive status could influence their performances, in terms of errors and time needed for the completion of the shopping task.

Methods

Participants

The sample consisted of aged volunteers recruited among participants of a randomized controlled trial (GR-2013-02356043, co-financed by the Italian Ministry of Health) aimed to assess the effectiveness of a 12-week intervention of cognitive stimulation and/or physical exercise in physical reality and non-immersive VR in preventing dementia or cognitive and functional decline. Since the aim of this study was to assess the acceptance of the proposed VR-based intervention in both a sample of MCI and SCD individuals, the fact that older adults were participating in a clinical trial was not believed to significantly influence the results. None of them declared having had previous experience with immersive VR technology.

Inclusion criteria were: age ≥ 60; Mini-Mental State Examination (MMSE) [42,43] score between 20 and 26 [44] (or 28 for people with 16 or more years of schooling [45]); subjective or objective impairment in at least one cognitive domain among memory, visuo-spatial abilities, language, attention or executive functions (objective cognitive impairment was operationalized as a score ≤ 1.5 standard deviations below the score obtained by the age-, sex-, and years-of-schooling-matched normative sample in at least one of the tests of the administered neuropsychological battery, (described in [46]); absence of a significant functional impairment, that was operationalized as a score < 9 in the Functional Assessment Questionnaire (FAQ) [47] or as a loss > 20% of functionality in the Instrumental Abilities of Daily Living (IADL) [48], good general health conditions, and the absence of any contraindications to moderate physical activity, certified by the general practitioner.

Exclusion criteria were: MMSE score < 20, significant functional impairment (FAQ ≥ 9 or IADL < 80% of the maximum obtainable IADL score); diagnosis of Alzheimer's Disease, dementia or other neurologic or psychiatric condition; suffering from a brain injury, cardiovascular diseases, or seizure; history of motion-sickness; sensorimotor dysfunctions or other health conditions that could prevent the execution of the tasks in VR.

Written informed consent was obtained prior to the participation in the study. The study was carried out in agreement with Helsinki declaration, and approved by the Ethical Committee of IRCCS Fondazione Santa Lucia.

Equipment

The Virtual Supermarket application was developed using Unity and deployed for the HTC Vive Pro. The HMD was equipped with room tracking units (infrared cameras) and two controllers allowing walking within the VE and interacting with the virtual objects. We used just one controller to limit the difficulties in the interactions [49].

The exercise was constituted by two scenes: the *aisle* scene and the *cash-register* scene. In the *aisle scene*, the VE emulated a supermarket aisle of 4 × 3 meters (figure 1.a.). Several grocery items were arranged onto two shelf units placed along the two longest walls. A shopping cart stood on one of the shorter sides of the corridor. On the trolley, a notepad with a list of 8 items to buy was presented. The user was requested to search for all the shopping items presented in the list and place them in the cart. In order to facilitate the task, two signs were positioned above the trolley, one on the right and one on the left. The list of the items that were placed in each lane was printed on the corresponding sign (Figure 1.a.). Alternative scenarios with a comparable degree of difficulty were created, so that the items to be purchased and their position varied from one session to the next.

The user was instructed to use a controller, which was similar to a small racket and visible in the VE, in order to interact with the virtual items. Holding the controller in his/her dominant hand, the participant could reach the virtual product, pick it from the shelf and put it in the cart. Each item emitted a slight vibration when reached by the controller, so as to give the user the impression of having touched it. The user then had to “grab” the item, by pressing a trigger button on the controller handle, to move it into the cart by keeping the trigger pressed, and to release it in the cart. The item could be released by releasing the trigger button: in this case, it fell following the laws of physics. If the user placed or dropped an object into the cart, it appeared as “bought”. If, he/she dropped it on the floor, the object remained visible on the floor for the entire shopping session and had to be picked up to be placed in the cart. Alternatively, it was possible to take the same type of item from those remaining on the shelf, even if this resulted in an error count.

The purchase of all the items on the list led to the transition to the *cash-register* scene. In this scenario, the cash register showed the amount to be paid (Figure 1.b.). The user had to select a combination of banknotes and coins to pay the total price, avoiding change. The conclusion of the correct payment determined the end of the trial: the user was then brought back to the *aisle scene*, and a new shopping list was generated to perform a new trial.

[Insert Figure 1 here]

Interaction data were collected and stored; such data comprised the time needed to complete each shopping list and the different types of errors. In the *aisle scene*, putting a product in the cart that was not on the list was counted as a *Wrong item Error* (WE); dropping an item on the floor was recorded as *Fallen item Error* (FE) if the object was subsequently picked up and placed in the cart, and as *Dropped item Error* (DE) if the object was left on the ground.

Protocol

Before starting the exercise, participants were told to perform the task as if they were in a real supermarket and instructed regarding the use of the controller in the two scenes. The entire experience lasted 15 minutes and consisted in the presentation of one or more shopping trials, composed of an *aisle* scene followed by a *cash-register* scene, depending on the speed of the participant. The entire exercise stopped automatically after the pre-set time, regardless of the number of trials performed by the participant, the type of scenario (isle or cash register scene) and the number of objects collected within the isle scene.

The duration of the experience was set according to what stated in the safety guidelines provided by head-mounted display manufacturers. Though standard cognitive sessions are usually longer, we did not expect any immersive VR-intervention to last longer, and thus to expose the participants to higher risks for their safety.

At the end of the test, participants were administered questionnaires aimed at evaluating their user experience.

Measures

The experience in the Virtual Supermarket was evaluated using both subjective and objective data. Regarding subjective opinions, participants completed the following questionnaires.

- The *Simulator Sickness Questionnaire* (SSQ) [50], was used to assess potential adverse effects of the virtual experience. The SSQ is composed of 3 different sub-scales: nausea (SSQ-N), oculomotor disturbances (SSQ-O), and disorientation (SSQ-D); each of the 3 sub-scales comprises 7 symptoms that may be rated as absent, slight, moderate, or severe. Though SSQ was developed in the context of driving simulators, this questionnaire is one of the most used for the assessment of cyber-sickness also non-driving scenarios [51]. Thus, its use allowed for the comparison with previous research.
- The *International Test Commission - Sense of Presence Inventory* (ITC-SOPI) [52] investigates SoP and focus on the user's experiences of media, with no reference to objective system parameters. It is composed of 4 sub-scales assessing *spatial presence* (SP, the sense of being immersed in the mediated environment, and of having control over it, 23 items), *engagement* (ENG, the sense of being psychologically involved in the virtual experience, 18 items), *naturalness* (NAT,

the sense of that the mediated environment is lifelike, 8 items) and *side effects* (SE, the adverse reactions to the presented environment, 6 items).

In addition, as older adults are generally considered not to be familiar with the use of VR, the administration of a questionnaire based on the Technology Acceptance Model (TAM3) [53] was included in the protocol, with the aim of investigating whether the presumed reduced confidence toward technology of elderly might have influenced the results of other scales. TAM3 allows for selecting just some items according to the objectives of the study; in this case, the following sub-scales were considered:

- *perceived usefulness* (PU), i.e., the extent to which a person believes that using an IT system will enhance his/her performances;
- *perceived ease of use* (PEOU), i.e., the degree to which a person believes that using a system will be effortless;
- *perception of external control* (PEC), i.e., the degree to which an individual believes that he/she has the resources to use the system;
- *computer anxiety* (CANX), representing the individual apprehension or fear that is perceived towards the technology;
- *perceived enjoyment* (ENJ), i.e., the extent to which the activity of using a system is perceived as enjoyable, regardless from the performances of the system itself.

- *output quality* (OUT), i.e., the degree to which an individual believes that the examined system performs satisfactorily.
- *behavioral intention* (BI), which outlines the willing of the individual to use the system in the future.

The answers in TAM3 were coded on a 7-item Likert scale, ranging from ‘strongly disagree’ (1) to ‘strongly agree’ (7).

The number of completed shopping sessions, execution times, WE, DE, and FE (performance) were also collected and stored.

Statistical Analyses

All the statistical analyses were performed using MATLAB 2019a Statistical Toolbox and considering a significance level equal to 0.05. Data from participants with MCI and SCD were analyzed separately. Cronbach’s alpha was used to assess the consistency of TAM3 subscales, as some of the TAM3 items were not included (according to Venkatesh et al. [53]). Pair-wise comparisons were made using unpaired t-tests and chi-squared tests for continuous values and frequencies, respectively. Since SSQ is known to have a skewed distribution [50], Wilcoxon rank sum test was used to compare SSQ results in the two groups.

Pearson’s correlations were used to evaluate the relation in between SoP and TAM3 subscales, and between these subscales and participants’ demographics, and objective performance variables. Significant simple correlations were tested for the effects of possible mediators by performing partial correlations.

Due to SSQ non-normality, Spearman's correlations were used to estimate the relation between SSQ subscales, SSQ and SoP, SSQ and TAM3; Spearman's correlation was used also for investigating the relation of SSQ with participants' age, gender, schooling and MMSE, and with objective performance variables (errors and timing).

Repeated measures ANOVA was performed to compare the time spent to complete each trial. Only times in the *aisle scene* were considered for the analysis, since the amount to pay in the *cash-register scene* was randomly generated, thus resulting in tasks of unequal difficulty; as a result, a comparative analysis on this data could not be performed.

Results

Fifty-eight seniors with MCI or SCD (26/32) were enrolled for this usability and acceptance study.

One participant with MCI fell without consequences during the trial. The participant reported being so immersed in the VR that he forgot that the surrounding environment was virtual: he tried to lean on a virtual shelf, in order to more easily grab an item, and this made him lose balance and fell.

One participant (SCD) interrupted the experience complaining discomfort, and did not fill the questionnaires. The results of this participant had thus to be excluded. Another participant (MCI) was excluded as the questionnaires were only partly filled. Final sample's characteristics are reported in Table 1.

Experience

Table 2 shows SSQ, ITC-SOPI and TAM3 results according to group belonging.

[Insert Table 1 here [54]]

The correlations among SSQ, ITC-SOPI and TAM3 subscale are presented in Table 2.

[Insert Table 2 here]

For MCI group, partial correlations confirmed only some of the correlations existing among SSQ subscales: SSQ-N and SSQ-O ($r = -0.97$, $p = 0.028$), SSQ-N and SSQ-D ($r = 0.96$, $p = 0.039$), SSQ-N and SSQ-TS ($r = 0.96$, $p = 0.038$); SSQ-O and SSQ-D ($r = 0.98$, $p = 0.016$), and SSQ-O and SSQ-TS ($r = 0.98$, $p = 0.016$).

For participants with SCD, partial correlation confirmed correlations among all SSQ subscales (SSQ-O with SSQ-D [$r = -0.65$, $p = 0.030$], and SSQ-TS with SSQ-N [$r = 0.81$, $p = 0.002$], SSQ-O [$r = 0.91$, $p < 0.001$], SSQ-D [$r = 0.87$, $p < 0.001$]), plus the correlations between PU and PEC ($r = 0.74$, $p = 0.006$); ENJ and SP ($r = 0.06$, $p = 0.040$); ENJ and ENG ($r = -0.60$, $p = 0.024$); ENJ and NAT ($r = 0.64$, $p = 0.022$); ENJ and CANX ($r = -0.72$, $p = 0.008$); ENG and BI ($r = 0.80$, $p < 0.001$).

Performance

On average, participants in the MCI group completed 3.45 ± 1.44 shopping sessions, i.e., each one bought 28 items on average, whereas participants with SCD ended 3.97 ± 1.70 lists, thus resulting in 32 bought items each; such disparity did not result in a significant difference. All the participants completed at least one trial (aisle + cash-register scene) within the 15 minutes. The maximum number of completed trials was 8 in both groups. The number of completed trials resulted negatively correlated with age for both the MCI ($r = -0.59$, $p = 0.003$) and the SCD ($r = -0.53$, $p = 0.002$) group. Also, in the case of SCD, years of schooling resulted significantly correlated with completed trial ($r = 0.37$, $p = 0.04$). No other significant correlation between demographic variables and completed trials emerged.

Execution times

The statistical comparison of trial's completion time was made including all the participants who completed the first four trials (n=10 for MCI group; n=21 for SCD), as did in [40]. Repeated measures ANOVA resulted in a significant main effect of time ($F_{HF}(2.49, 24.05) = 16.69$, $p < 0.001$), indicating that participants improved their performance across trials; post-hoc tests highlighted that execution times for the first trial resulted significantly higher than those of all the subsequent trials ($p = 0.017$, for the second; $p < 0.001$ for the third and the fourth).

Group had no effect ($F_{HF}(0.83, 24.05) = 2.19$, $p = 0.15$), both when considered alone, and in the interaction with time ($F_{HF}(2.49, 72.16) = 0.11$, $p = 0.956$).

For MCI group, a positive correlation was observed between age and execution times for the second ($r = 0.55$, $p = 0.007$) and the third ($r = 0.58$, $p = 0.009$) trials.

Also for SCD group, age and trials' execution times were correlated; however, in this case, correlation reached significance for the first ($r = 0.36$, $p = 0.047$), and the third ($r = 0.41$, $p = 0.043$) trials. Years of schooling were, instead, correlated negatively with execution times in for the first ($r = -0.38$, $p = 0.035$) and the second trial ($r = -0.53$, $p = 0.004$).

Excluding the duration of the other trials, the only correlations that were confirmed were the ones with age, and only in the case of SCD (first trial: $r = 0.475$, $p = 0.463$; third trial $r = 0.52$, $p = 0.025$).

Errors

One third (n=8) of the participants in the MCI group, and 45% of the participants in the SCD group (n=14) put in the cart at least one wrong object (or a duplicate of an already bought product) during the first trial; 66% participants in the MCI group (n=16) and 87% in the SCD group (n=27) dropped at least one item during the first trial.

Relative errors with respect to the trials completed by the participants are reported in Table 3.

[Insert Table 3 here]

Considering the mean errors per trial for each participant, no significant differences were found between the MCI and the SCD groups.

Instead, a few correlations with questionnaire data and demographic characteristics emerged. For the MCI group, WE was correlated with CANX ($r = 0.64$, $p < 0.001$), FE with CANX ($r = 0.44$, $p = 0.032$), DE with PEOU ($r = -0.44$, $p = 0.031$) and with PEC ($r = -0.44$, $p = 0.030$). Interestingly, DE was also negatively correlated to MMSE ($r = -0.45$, $p = 0.028$). With regard to the SCD group, years-of-schooling and WE were negatively correlated ($r = -0.46$, $p = 0.010$).

Discussion

This study investigated the acceptance of a cognitive intervention based on immersive VR in participants with objective or subjective cognitive decline. To our knowledge this was one of the first studies addressing the acceptance of an immersive VR environment that required walking and active interaction among older adults, and the first specifically comparing the differences between older adults with MCI or SCD in terms of user experience.

The two groups we enrolled were comparable in terms of gender distribution, age, years-of-schooling. Clearly, MMSE scores were significantly different between the two groups. We had hypothesized that the Virtual Supermarket would be enjoyable for the participants irrespective from their cognitive status, and that reduced side-effects, high levels of SoP, and good acceptance of technology would be observed.

Our hypotheses seemed to be confirmed; in fact, SSQ scores were lower than values commonly recognized as “acceptable” (i.e., < 15 [50]) probably because no sensory mismatch occurred, since the navigation in the environment was the result of walking [21]. Also SE scores were lower than what observed in previous studies, (e.g., Nielsen et al. [55]), that compared different rendering means, among which immersive VR. No difference in SSQ reached statistical significance between the two groups, but participants with SCD appeared to suffer more from both oculo-motor disturbances (SSQ-O) and dizziness (SSQ-D). In both groups, we found that higher scores were associated to those of the SSQ-D subscale; this observation was in agreement with previous studies, which identified dizziness and vertigo as the major distinguishing features of cyber-sickness, when no vection occurs [56].

Our data was also consistent with previous studies showing that susceptibility to sickness decreases throughout life [25], and evaluating the effects of non-interactive immersive VR on a sample of older adults [23]. There were studies in which a dependency was found, but in all those cases the environment was specifically designed to elicit symptoms [57,58]. In contrast, this was not our aim, and we recorded very light malaise.

The fact that symptoms were too light to highlight any correlations could be worthy also for MMSE score. Having found that no correlations exist, it could be argued that immersive VR may be used safely by older adults suffering from MCI; however, further studies are surely needed, also considering that memory, judgement defects, or the potential occurrence of postural instability consequent to prolonged VR immersion may increase the risk of adverse events [35]. In addition, it is plausible that they may experience some issues in the interaction with virtual objects (see further).

Regarding SoP, ITC-SOPI scores obtained by the two groups were superior than what reported by Nisenfeld et al. [55] who also evaluated physical reality, and comparable with what obtained by younger adults experiencing the same environment [40]. Neither age-related, nor cognitive status-related negative attitude toward technology emerged in this study. The good levels of realism reached by the Supermarket were also confirmed by the falling of one participant, who felt so immersed that he forgot to be in a virtual scenario; as he wanted to lean on the shelf, we could confirm that his/her behavioral response was the same he would have employed in the physical world [59]. Though this could be interpreted as a (positive) sign of high realism, it opened the way to a series of implications for the employment of immersive VR in the training of seniors with objective (or subjective) cognitive decline.

Regarding possible correlations with participants' demographic characteristics, we found that SP resulted influenced – only for the SCD group – by sex, and, in particular, that it was higher for males. In literature, the correlation of the quality of the experience with sex is still debated. There are studies reporting better experiences for males [60] and others highlighting that women are more susceptible to virtual environments exposure; in particular, females appear to experience higher SP and NAT, but also more side-effects

[61–63]. An hypothesis has been made that males engage in presence via the interaction, whereas women tends to rely more on visual feedback only [64]; in our case, the interactions with grocery items may have caused the higher SoP recorded for men. Nonetheless, our outcomes must be treated carefully, as the sample was small (i.e., 22 F and 9 M), and the same tendency was not recorded in the MCI group.

The last subjective variable evaluated in this work was technology acceptance; this variable is fundamental to evaluate the meaningfulness of technological solution to a specific target group, and thus if they are prone to use it in daily life [53]. Also in this case, our hypothesis was confirmed: all positive sub-scales were rated > 5 out of 7 points. Thus, it could be deduced that the system was easy to use (PEOU) and to learn, and perceived as potentially useful (PU) [65,66].

Looking more in details at TAM3 subscales, we found that PEC was higher for males with MCI, and lower for participants with more severe symptoms of cognitive decline. Also, ENJ was lower for older participants with MCI, and higher for the ones more educated. Whereas the relation between the quality of the experience and sex is unclear, it is plausible to believe that only seniors with MCI would have perceived some issues in the interactions within the environment (i.e., PEC) because of their cognitive impairments [67]; in turn, this may have negatively influenced their enjoyment too [68].

Age also had a negative effect on the participants' enjoyment (i.e., ENJ) in individuals with MCI. This may be due to a negative attitude or a lack of familiarity with technology, which has been proven to be reduced in the case of individuals with cognitive decline [23,69]. Negative attitude toward ICT technologies may also be the result of less education [70].

Regarding the correlations among subjective variables, we found a general pattern in which positive feelings (i.e., SP, ENG, NAT, ENJ) and variables related to the acceptance of technology (i.e., PEOU, PEC, BI) were positively reinforced, whereas positive feelings, and experience drawbacks (i.e., SSQ subscales, SE) and computer anxiety (i.e., CANX) tended to diverge.

No specific conclusions can be drawn by looking at the differences between the two groups, if not the fact that the general quality of experience was probably influenced by different factors; e.g., participants with MCI reported higher enjoyment (ENJ) only in relation to higher control (i.e., PEC), whereas the SCD group' ENJ was also significantly influenced by SP, ENG and NAT. It was interesting also to notice that PEOU was negatively influenced by physical drawbacks (SSQ-N, SSQ-D, SSQ-TS for SCD, and SE for MCI). This probably meant that participants perceived a sense of slight (and perhaps not aware) unease that partially decreased the easiness of use of the virtual environment [71].

In general, however, no specific difficulties were encountered, and none of the participants asked for help to interact with the controller. The easy process of learning was confirmed also by the longer time needed to complete the first trial, and the decreasing number of relative errors throughout trials.

In a few cases, the number of errors were also distinctive for the participants' cognitive status: in the first two trials (and in the fourth), seniors with MCI put in the cart a number of wrong (or duplicated) items that was significantly higher with respect to what done by participants of the SCD group. Performing the assessment of participants' cognitive status was not in the scope of this work; nonetheless, this outcome could constitute a potential starting point to perform the assessment of patients' cognitive status throughout the different training sessions.

Another interesting element emerging from errors analysis was that errors were often related to computer anxiety (i.e., CANX), and reduced sense of control (i.e., PEC). This outcome could support the hypothesis of lack of familiarity [23,70], which in turn had resulted in higher anxiety in the interaction with a new and not previously experienced technology [53].

In terms of participants' personal characteristics, we hypothesized that age, education and cognitive status would have influenced the performances within the environment. Our hypothesis was partially correct. In fact, age was correlated to the number of completed trials and to the time required to complete (some of) them – though with a few differences between MCI and SCD; this may result from the fact that older participants approached the technology with more caution, probably – once again – because of their less familiarity with VR tools [23,70]. Another hypothesis could be related to the reduced quality of sight, which has been proven to decrease with age [72]: less visual acuity may also influenced the time required to search and grab objects within the scene. Future studies should thus consider also this aspect when collecting participants' characteristics.

In the case of participants with SCD only, also years-of-schooling emerged as an important factor: more educated participants took less time to complete trials, and also committed less errors in product picking (i.e., WE). This was in agreement with previous findings indicating that more educated individuals are more prone to use technology in daily-life contexts [70].

The negative correlation between MMSE and dropped (and not recollected) items, instead, appeared less explicable. Though further studies are surely needed to confirm it, it is possible to hypothesized that participants with more severe symptoms, being aware of their status, have paid more attention to their actions, with the goal of increasing safety margins during object manipulation [73].

Limitations

We acknowledge that our work had some limitations. The first is related to the choice of participants; the fact of being enrolled in a RCT in which computerized technologies were used may have introduced a bias in the evaluation of the acceptance of immersive VR technology and in the performances of our participants. They may have shown more positive attitude toward the proposed solution, and higher efficiency in the accomplishment of the shopping task, due to their previous experience. Also, we did not apply any qualitative instruments (e.g., thinking-aloud protocol, or interviews) to better unveil potential difficulties and emotions arising during the navigation within the Virtual Supermarket. However, the analysis of standardized questionnaires and the consistency of the data we collected (e.g., Cronbach alphas' values, the existence of meaningful correlations between examined variables) may be interpreted as points of strength.

Conclusions and future directions

This study assessed the acceptance and the usability of an immersive VR application in older adults with MCI or SCD. With respect to previous studies [23,36], our experience required the active and purposeful participation of the participants, who walked around and interacted with the objects in the scene.

Thus, it plausible to hypothesize that also other immersive environments having the same features of the Virtual Supermarket (i.e., navigation occurring with walking, control over the interactions with virtual objects) will be accepted and considered enjoyable by older adults, also in the case of objective cognitive impairment.

Given our experience, however, we suggest to ensure the safety of standing or waking individuals immersed in VR by introducing a harness (or specific VR-dedicated solutions), which could exclude the risk of falling in the case of dizziness, disorientation, or tripping of the participant.

Further studies comprising a larger sample (including also people with different diagnosis, and not taking part in any studies), and more sessions are thus required to shed light on the acceptance of interactive immersive VR in the non-pharmacological treatment of MCI. Also, it would be interesting to couple subjective (i.e., SSQ) and objective measures: body sway, heart and breath rate, electroencephalography and electrogastrography are all non-invasive techniques that could be used to further study the acceptance of immersive VR programs [20,21].

Once that the acceptance is ensured, randomized clinical trials could be implemented to test the effectiveness of these interventions.

Authors' contributions: SA, SGDS, MM and LG conceived and designed the study. SA and LG implemented the virtual environment; SGDS, FF, BF, ML, FR enrolled and evaluated the sample and carried out the experiment; SA and MM performed the data analysis. SA, SGDS and FF wrote the first draft; all the authors revised the manuscript. GF, MS and LG supervised the study.

Ethical approval: All procedures performed involving human participants were in accordance with the ethical standards of Fondazione Santa Lucia research committee, and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Tables

Table 1. Characteristics of the samples. *: significant difference at t-test .

	MCI (n = 24)	SCD (n = 31)	
Age	72.45 (5.83)	70.67 (5.62)	t = 1.15 p = 0.26
Sex (M/F)	11/13	22/9	$\chi^2 = 3.56$ p = 0.59
Years of schooling	12.38 (3.86)	13.48 (3.58)	t = 1.10 p = 0.28
MMSE	26.63 (1.85)*	27.91 (1.67)*	t = 2.67 p = 0.01

Table 2. For SSQ data are reported as median value (iqr), the others as mean (standard deviation).

		MCI		**SCD**		**Pair-wise comparison**
Scale	**Sub-scale**	**Value**	**Cronbach' α**	**Value**	**Cronbach' α**	**p-value**
SSQ	SSQ-N	0 (9.54)		0 (9.54)		0.174
	SSQ-O	0 (9.48)		7.58 (18.95)		0.331
	SSQ-D	0 (13.92)		13.92 (27.84)		0.085

	SSQ-TS	3.74 (9.35)		11.22 (18.70)		0.090
ITC-SOPI	SP	3.59 (0.43)		3.45 (0.55)		0.313
	ENG	3.72 (0.50)		3.95 (0.79)		0.228
	NAT	4.02 (0.84)		3.74 (0.79)		0.217
	SE	1.38 (0.53)		1.52 (0.54)		0.342
TAM3	PU	5.31 (1.40)	0.93	5.10 (1.41)	0.94	0.576
	PEOU	6.16 (0.82)	0.76	6.37 (0.67)	0.60	0.330
	PEC	5.40 (1.24)	0.68	5.78 (1.25)	0.81	0.264
	CANX	2.06 (1.24)	0.76	1.71 (1.35)	0.82	0.323
	ENJ	6.42 (0.64)	0.96	6.35 (0.77)	0.89	0.743
	OUT	5.92 (1.08)	0.78	5.64 (1.00)	0.70	0.329
	BI	5.09 (1.87)	0.94	5.53 (1.41)	0.92	0.336

N: nausea;
O: oculomotor disturbances;
D: disorientation;
SP: spatial presence;
ENG: engagement;
NAT: naturalness;
SD: side-effects;
PU: perceived usefulness;
PEOU: perceived ease-of-use;
PEC: perception of external control;
CANX: computer anxiety;
ENJ: perceived enjoyment;
OUT: output quality;
BI: behavioral intentions.

Table 2. Correlations between sample's demographic characteristics, SSQ, ITC-SOPI and TAM3 subscales, divided according to group MCI and SCD. Bold text is used to highlight significant correlations; * $p < 0.05$, ** $p < 0.001$.

		age	gender	MMSE	y.o.s.	SSQ-N	SSQ-O	SSQ-D	SSQ-TS	SP	ENG	NAT	SE	PU	PEOU	PEC	CANX	ENJ	OUT	BI
gender	MCI	0.07																		
	SCD	0.23																		
MMSE	MCI	-0.13	-0.24																	
	SCD	-0.23	-0.12																	
y.o.s.	MCI	-0.30	-0.12	-0.04																
	SCD	0.04	0.11	0.09																
SSQ-N	MCI	0.17	0.10	0.15	0.03															
	SCD	-0.17	-0.15	0.04	-0.30															
SSQ-O	MCI	-0.08	0.02	-0.01	-0.06	**0.46***														
	SCD	-0.27	-0.10	-0.06	-0.31	0.34														
SSQ-D	MCI	0.12	0.09	-0.15	-0.24	**0.45***	**0.85**§													
	SCD	-0.31	-0.27	-0.06	-0.19	0.35	**0.71**§													
SSQ-TS	MCI	0.08	0.03	-0.04	0.01	**0.67**§	**0.94**§	**0.84**§												
	SCD	-0.30	-0.18	-0.04	-0.34	**0.60**§	**0.90**§	**0.86**§												
SP	MCI	-0.12	-0.16	0.05	-0.29	-0.15	-0.11	0.11	-0.16											
	SCD	0.06	**0.44***	-0.24	-0.04	0.11	-0.23	-0.07	-0.09											
ENG	MCI	-0.02	-0.13	-0.02	-0.35	-0.29	-0.20	-0.16	-0.28	**0.44***										
	SCD	-0.15	0.12	-0.23	-0.06	0.05	-0.12	-0.03	-0.04	**0.68**§										
NAT	MCI	0.18	-0.17	0.00	-0.40	-0.14	-0.04	0.00	-0.10	**0.59***	0.13									
	SCD	0.02	0.31	-0.32	-0.05	-0.05	-0.17	-0.01	-0.09	**0.75**§	**0.62**§									
SE	MCI	-0.17	0.01	0.26	0.38	**0.50***	**0.44***	0.26	**0.47***	**-0.44***	-0.16	**-0.62***								
	SCD	-0.12	-0.09	0.03	-0.22	**0.49***	0.33	**0.48***	**0.52***	0.26	0.32	0.25								
PU	MCI	0.15	0.06	0.28	-0.26	0.20	-0.14	-0.05	-0.09	0.04	0.19	0.08	-0.07							
	SCD	0.04	0.22	-0.11	-0.01	-0.25	-0.04	-0.07	-0.08	0.04	-0.01	0.15	0.03							
PEOU	MCI	-0.12	0.24	-0.32	-0.15	-0.25	0.10	0.19	-0.03	0.18	0.05	0.12	**-0.46***	-0.07						
	SCD	0.04	0.29	-0.23	0.20	**-0.41***	-0.26	**-0.41***	**-0.38***	0.05	-0.08	0.16	-0.33	**0.55***						
PEC	MCI	-0.01	**0.52***	**-0.68**§	-0.09	-0.01	0.01	0.08	0.02	-0.21	-0.16	-0.11	-0.27	-0.15	**0.41***					
	SCD	-0.02	-0.10	0.13	0.18	0.10	0.07	0.07	0.11	-0.07	0.02	-0.23	-0.06	**0.41***	0.02					
CANX	MCI	0.12	-0.24	0.05	-0.09	0.38	0.07	0.00	0.17	0.15	-0.04	0.12	0.16	0.24	-0.26	-0.10				
	SCD	-0.08	0.01	0.11	-0.09	**0.45***	0.22	0.30	**0.38***	0.03	0.08	-0.01	0.61	-0.18	-0.35	-0.04				
ENJ	MCI	**-0.57***	0.29	-0.14	**0.45***	-0.30	-0.05	-0.07	-0.15	0.03	0.01	-0.25	0.09	-0.17	**0.53***	0.39	-0.21			
	SCD	0.01	0.01	-0.08	0.07	-0.20	-0.26	-0.14	-0.20	**0.36***	**0.36***	**0.49***	-0.21	0.23	**0.36***	0.11	**-0.41***			

OUT	MCI	0.14	0.14	-0.04	**-0.47***	-0.07	-0.07	0.10	-0.10	0.26	0.16	0.20	-0.34	0.24	0.11	0.33	-0.19	0.02		
	SCD	0.15	0.05	-0.22	-0.06	0.05	0.03	0.05	0.10	0.20	0.31	**0.38***	0.06	0.33	0.34	-0.09	-0.24	**0.36***		
BI	MCI	-0.09	0.30	-0.04	**-0.59***	-0.11	-0.11	0.03	-0.19	0.41	**0.56***	0.35	-0.33	0.14	0.06	0.19	-0.10	-0.05	0.29	-
	SCD	-0.15	0.08	-0.24	-0.11	0.20	0.10	0.07	0.13	0.07	**0.50***	-0.01	-0.03	-0.22	-0.09	0.08	0.02	0.01	0.22	-

N: nausea;
O: oculomotor disturbances;
D: disorientation;
SP: spatial presence;
ENG: engagement;
NAT: naturalness;
SD: side-effects;
PU: perceived usefulness;
PEOU: perceived ease-of-use;
PEC: perception of external control;
CANX: computer anxiety;
ENJ: perceived enjoyment;
OUT: output quality;
BI: behavioral intentions.

Table 4. Relative errors for each trial. * $p < 0.05$; § $p < 0.001$.

	Trial	1	2	3	4	5	6	7	8
WE	**MCI**	1.00*	0.69*	0.26	0.80*	0.33	0	0	0
	SCD	0.77*	0.29*	0.24	0.33*	0.17	0	0	0
FE	**MCI**	0.38	0.30	0.21	0.30	0	0.5	0	1.00
	SCD	0.23	0.22	0.16	0.19	0.33	0.20	0	0
DE	**MCI**	1.04	0.78	1.05§	0.30	0	0	1.00	0
	SCD	1.23	0.56	0.48§	0.52	0.50	0.20	2.00	1.00
Part.	**MCI**	24	23	19	10	3*	2	1	1
	SCD	31	27	25	21	12*	5	1	1

WE: wrong item errors;
FE: fallen item errors;
DE: dropped item errors;
Part: the number of participants who completed the trial.

Figures

Figure 1. The aisle (a.) and the cash-register (b.) scenes. Below, two participants experiencing the interaction with the Virtual Supermarket (c; d).