The Efficacy of Virtual Reality-Based Cognitive Training in Older Adults Non-Demented and with Mild Dementia: an One Group Pretest-Posttest Design

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Abstract

Background Current methods of cognitive interventions for older adults are increasingly employing modern technologies. However, research into possible applications of virtual reality (VR) in such interventions has begun only recently. The aim of the study was to evaluate the efficacy of VR-based cognitive training for older adults and to compare this efficacy in older adults without cognitive impairment and with mild dementia. Methods The complete data were obtained from 99 individuals aged 60-89, qualified according to Mini Mental State Examination (MMSE) scores into the group of non-demented older adults (n=72, mean age 68, MMSE: 28-30) or older adults with mild dementia (n=27, mean age 72, MMSE: 19-23). An one group pretest-posttest design was applied. Cognitive training with the use of GRADYS software – a computer game with elements of VR was introduced in all participants. The game included four modules corresponding to: attention, memory, visual processing and language. The intervention lasted 4 weeks and consisted of eight sessions, two per week. The intervention program was preceded and followed by a cognitive assessment of processes corresponding to the modules of the game. The following statistical tests were used: the repeated measures multivariate analysis of variance supplemented with one-way tests, the Hotelling T2 test, the Student's t test, the Friedman test, the Mann-Whitney U test, the Kruskal-Wallis test. Results Both research groups demonstrated progress in the training, which was greater in non-demented older adults for the majority of cognitive modules except for the attention module. There were also significant differences in general cognitive functioning before and after the training. However, positive changes in cognitive performance in particular tests were revealed almost exclusively in the group of older adults without cognitive impairment. There was no relationship between the level achieved in particular training modules and the improvement in corresponding cognitive tasks. Conclusions Currently, we can recommend the GRADS game for use only in non-demented older adults. The hypothesis of the presumable usefulness of the game in individuals with MCI needs to be tested. In turn, the application of the GRADYS game to people with dementia would require modification of the hardware and software.

Background

The dynamic development of modern technologies raises questions as to the possibilities, benefits and limitations of their application among the older adults due to the developmental changes in the sensorimotor abilities, cognition and motivation observed in this age group (1). Although seniors proved to be late adapters to the world of modern technologies, the fact remains they effectively use those technologies for their own health protection and promotion, for instance telemedicine, e-health (2).

An important area for modern technologies application in older adults is improving their cognitive functioning through cognitive interventions (CI), including cognitive training (CT), cognitive stimulation (CS) and cognitive rehabilitation (CR) (3). As people get older, many cognitive abilities deteriorate and the process is referred to as cognitive ageing (4). It mostly affects memory processes, learning, attention, reasoning and executive functions (5, 6, 7). What is more, the risk of dementia disorders increases with age in the course of various neurodegenerative diseases (8, 9). Deterioration in cognitive functioning of an older adults results in their reduced independence, lower self-esteem and withdrawal from many areas of activity (professional, social and educational) due to deterioration in mental functions. In view of the above, studies into possible forms of non-pharmaceutical interventions aiming to maintain, improve or enhance cognitive performance, and prevent its deterioration in senior age gain particular relevance.

Research on the methods improving cognitive performance in cognitively healthy older adults and in persons with cognitive impairment, including dementia, have been conducted for many years now and have provided evidence of the effectiveness of various cognitive interventions (10).

For example, the meta-analysis of randomized controlled trials by Chiu and colleagues (11) indicated that CT is effective for non-demented older adults. Similarly, the review of research on CS and CT programs for healthy older participants performed by Tardif and Simard (12) pointed out that the results are promising for memory, attention, executive functions, and speed of processing. Also meta-analyses of the influence of process-based CT, like working memory or cognitive control training, in healthy older adults demonstrated the effectiveness of such CI (13, 14). Moreover, CT enhance stability of cognitive functioning across adulthood, as indicated the review by Eschen (15). According to this review all types of CT enhanced absolute stability of cognitive functioning, but the greatest effects were reported for process-based CT. What's more, findings of a few studies discussed in this review demonstrated that thanks to CT also the absolute stability in brain functioning across adulthood can increase. Also systematic review of randomised controlled trials with longitudinal follow-up revealed that CT can prevent the onset of dementia in healthy older adults (16). CT induced strong and persistent protective effects on longitudinal neuropsychological performance. Some studies considered in this review reported also transfer of training effects to general cognition and daily functioning.

Moreover, CI may be beneficial not only in normal ageing process, but also in the case of MCI. The results of all CI in cognitively healthy older adults and older adults with MCI between 1970 and 2007 reviewed by Martin et al. (17) suggest that CI lead to performance improvements and that the size of the effects differs for different kinds of memory skills in non-demented older adults and people with mild cognitive impairment (MCI). Systematic review of 10 studies, followed by effect sizes analysis found that CT (including cognitive exercises and memory strategies training) can produce moderate-to-large positive effects on memory-related outcomes in older adults with MCI (18). Positive influence of CI, including CT, on various aspects of memory, attention and executive functions in older adults with MCI was pointed out also in other review (19). Mewborn, Lindbergh and Stephen Miller (20) analysed 279 effects from 97 studies on CT in older adults. Overall, results indicated that CT produce a small, but significant, improvement in the cognitive functioning of older adults, relative to active and passive control groups. At the same time, cognitive status (cognitively healthy vs. MCI), as well as age and education were not significant moderators. Effects were larger for directly trained outcomes but were also significant for non-trained outcomes (i.e. transfer effect). However, not all reviews and meta-analyzes on the effects of CI in individuals with MCI lead to such optimistic conclusions. A meta-analysis on memory training effects pointed out the scarce of evidence of the effectiveness and specificity of such CT in older adults without cognitive impairment and with MCI (21).

Going further, the results of research on the possibility to improve cognitive functioning under the influence of CI in persons with dementia are less clear. Some reviews and meta-analyzes indicated positive effect of CI on cognitive functioning in dementia (22, 23, 24). Based on the analysis of randomized controlled trials, Ballard and colleagues concluded, that modest but significant benefits in the treatment of cognitive symptoms in people with Alzheimer's disease (AD) can be achieved through various CI, including CT, CR and CS (25). Also the systematic review of the literature and meta-analysis of the effect of CT on multiple functional domains in AD patients showed medium effect sizes for learning, memory, executive functioning, activities of daily living, general cognitive problems, depression, and self-rated general functioning (26). According to the scoping review on the effects of non-pharmacological interventions for adults with mild cognitive impairment and early stage dementia, CI focused on remediation caused a little improvement in selected cognitive abilities, in turn cognitive training focused on compensation influenced the impact of cognitive changes impact on daily living (27). The effect sizes were however small. Moreover, most of the studies included in this review concerned MCI patients. The review comprised 20 studies in persons with MCI, only 8 studies in persons with early AD and 4 studies involved both, MCI and early AD patients. Other authors pointed out that convincing evidence of clinical significance for the impact of CI in cognitively impaired older adults was only obtained from single trials in terms of delay of cognitive decline, improvement in activities of daily living, or enhanced attainment of personally relevant goals (28). Furthermore, if CI types are distinguished, i.e. CT, CS and CR, it turns out that in people with dementia they vary in terms of effectiveness. Meta-analysis and meta-regression by Huntley and colleagues found the significant positive effect of CS on general cognitive functioning in dementia, but no evidence for the positive influence of CT or mixed approach, combining CT and CS (29). Also according to review by Bahar-Fuchs, Clare and Woods (30), CT is not associated with positive or negative effects on cognitive functioning in persons with mild to moderate dementia. In the review on CI in cognitively impaiered older adults authors firstly concluded that CI improve global cognitive functioning in patients with MCI or AD and their abilities of daily living, reduce behavioural disturbances, and have positive effects on quality of life. Secondly, authors noticed the varying effectiveness of particular types of CI, depending on the level of cognitive deficits. Patients with mild to moderate dementia benefited more from CS, while older adults with MCI from CT (31). It corresponds to the conclusions from the systematic review of 11 CT studies and 7 CS studies in individuals with dementia (32). In this review evidence for efficiency of CT among demented persons proved to be insufficient and doubtful. Contrary, for CS there was good evidence for general cognitive enhancement, more specifically in language and memory.

Currently, an increasing number of research concerns the efficacy of CI using modern technologies, like computerized cognitive training (CCT) or video games (VG). A systematic review on efficacy CCT for cognitively healthy older adult indicated that findings are comparable or better than those from reviews of more traditional, "paper-and-pencil" CT approaches (33). The authors concluded that computerized training may be an effective alternative. Lampit, et al. (34) reviewed the results of fifty-two studies on the effectiveness of CCT encompassing 4,885 healthy older adults. The overall effect size for CCT versus control was small but statistically significant. Small to moderate effect sizes were found for nonverbal memory, verbal memory, working memory, processing speed and visuospatial skills. No significant effects were found for executive functions and attention. According to the systematic literature review and meta-analysis by Tetlow and Edwards (35) commercially available CCT can improve cognitive abilities in older adults, who also report improvement on tasks relevant to their everyday lives. Other systematic review on clinical significance of commercially available computerized "brain training" programs was summarized by the authors' conclusion that at least some of such CT software is effective and can supporting healthy ageing (36). Moreover, Edwards et al. (37) conducted a systematic review and meta-analyses of Useful Field of View (UFOV) CT, and their results indicated that UFOV CT enhanced neural outcomes, speed of processing, and attention and showed far transfer to everyday functioning. UFOV CT effects were equivalent when compared to active- or no-contact control conditions. Moreover, improvements on the trained skills endured across ten years. Admittedly, they did not transfer to other neuropsychological outcomes, however positively enhanced well-being, health, and quality of life. A systematic review and meta-analysis on computer-based CI for people with dementia proved that these CI have moderate effects in cognition and mood but not on activities of daily living (38). A PRISMA-compliant network meta-analysis led to conclusion that in older adults with MCI and AD optimal intervention for cognitive performance is physical exercise, whereas CCT is the optimum for neuropsychiatric symptoms (39). This meta-analysis also showed that nonpharmacological therapies are better than pharmacological therapies in MCI and AD patients. Another meta-analysis concerned the efficacy of CCT in people with MCI or dementia indicated moderate overall effect on cognition in MCI and small to moderate effects for global cognition, attention, working memory, learning, and memory, with the exception of nonverbal memory (40). In turn in dementia, statistically significant effects were found on overall cognition and visuospatial skills, but the last ones were driven by trials of VR or VG. The authors concluded that CCT is efficacious in people with MCI but evidence for efficacy in people with dementia is weak and limited to trials of immersive technologies. The newest scoping review on non-immersive brain gaming for cognitively impaired older adults showed that most brain gaming interventions with the use of computer and/or touch screen led to improvement in at least one cognitive outcome (41). Going further, according to this review in older adults with MCI it was possible to get the near transfer effect by training in processing speed, memory, attention, and working memory, the far transfer effect by training in attention and working memory, and improvement in functional activities by training in visual processing speed and attention, or working memory. In turn, in older adults with dementia the supervised brain gaming training in memory, executive function, and language led to the near transfer effect. The conclusion of the authors points to the potential of brain gaming in the improvement of cognitive functioning in older adults with mild to severe cognitive decline. As regards VG, from a meta-analytic study on the enhancement of cognitive functioning in healthy older adults under influence of VG-based CT followed that such training induces positive changes in reaction time, attention, memory, and global cognition (42). The research by Wang, Zhu, Qi, Huang, and Li (43) proved that VG experiences may have a positive influence also on the brain activation underlying cognitive performance. Their results showed that healthy older VG players presented significantly better cognitive performance than non-VG players and greater brain activity, mainly in frontal-parietal areas.

Along with the intensive development of modern technologies, more and more advanced solutions are becoming available. In this context the use of VR in the CI is a new research area arousing growing interest. VR can be defined as "an advanced form of human-computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion" (44, p. 298). Currently the standard for fully immersive VR are head-mounted displays (HMDs) because they provide the greatest level of immersion. Besides HMD, VR can be implemented by world-fixed displays taking many forms, from a standard monitor to displays completely surrounding the user e.g., CAVEs, and hand-held displays, like smartphones or tablets (45, 46). Evidence is accumulating showing that VR-applications can successfully be employed for early detection and monitoring of physical and cognitive impairment (47, 48, 49, 50), but also for interventions in a wide range of medical conditions, like chronic pain, obesity, eating disorders, anxiety, phobia, depression, schizophrenia, autism, behavioural disorders and cognitive disorders of various etiologies (51, 52, 53, 54, 55, 56, 57).

One major benefit of VR-based CT is that it addresses previous criticisms about CCT by providing individuals with an intervention that is immersive, naturalistic, and mimics real-time and real-life, increasing ecologic validity (54, 58, 59, 60). Ecological validity provided by VR can be seen as a key component for assessing and training cognitive skills that are relevant for functional tasks in real-world contexts (61, 62, 63).

Moreover, it is worth to be noted that VR applications like VG and CCT create favourable conditions to implement the rules of so called serious games in CT for older adults (64, 65). Serious games have been used in the field of neurodegenerative disorders such as Alzheimer's disease to support and improve the assessment of different functional and cognitive abilities, and to provide alternative solutions for patients' rehabilitation. Results confirmed that SG are also adapted to older people with MCI (66).

In summary, currently VR technology is considered as one of the most promising tools for providing nonpharmacological cognitive interventions for cognitively healthy older adults and persons with different level of cognitive impairment (54, 67).

Nevertheless, research on the effectiveness of VR-based CT is still scarce, all the more so in the group of older adults and in relation to cognitive ageing. For example in the systematic review of VR applications in inpatient medical settings between 2005 and 2015, only one of 11 studies included in the review concerned cognitive rehabilitation. This study was however not focused on cognitive ageing. It involved 18 patients with traumatic brain injury, aged 19–73 years (51).

The efficacy of CCT and VR-based CT in older adults with MCI or dementia was assessed in systematic review by Coyle, Traynor and Solowij (68). The cognitive domains of attention, executive function, and memory (visual and verbal) showed the most consistent improvements, including long-term effects. CCT and VR-based CT were however moderately effective in long-term improvement of cognition for those at high risk of cognitive decline and did not improve the activity of daily living. It should be noted that only three studies using VR-based CT were taken into account in the systematic review, although the authors pointed out that the review was undertaken following a wide search of the available literature on the topic area. It indicates the small number of studies carried out so far on this topic.

Recently, several studies have been published, the results of which are generally promising. However, the study samples are usually small, including case studies and articles describe pilot studies or even the research plan with only partial results from initial phases of the study which are continued (61, 69, 70, 71). It is recommended that research into possible applications of VR in CI shall be conducted because of the preliminary nature of most data currently available in this area and a relatively small number of studies carried out so far (54, 68).

Methods

The aims and study design

The aim of the study was to evaluate the efficacy of the VR-based cognitive training in persons aged 60 and above without cognitive impairment and with mild dementia.

In our research we have posed the following hypotheses:

1. In the process of training using GRADYS game an improvement in the performance of the training tasks will occur, manifested in reaching higher levels of the game difficulty in each of the training modules, regarding: memory, attention, language, visual processing.
2. The effect of the training will result in an improvement in cognitive performance beyond the game environment, i.e. in the performance of standard cognitive measures of memory, attention, language and visuospatial processing.
3. Belonging to the group of older adults without cognitive impairment vs. older adults with mild dementia will differentiate the participants in terms of cognitive performance in pretest and in terms of training effects. The cognitive performance in pretest will be better in non-demented older adults compared to participants with mild dementia. Training effects in both groups will be significant and positive, as described in hypotheses 1 and 2, but in the group of non-demented older adults they will be greater.
4. There will be a positive relationship between the progression in the training and the improvement of cognitive performance beyond the game environment, i.e. participants with greater achievements in training will demonstrate a greater improvement in cognitive performance beyond the game environment.

An uncontrolled pretest-posttest study design was applied. The GRADYS game was tested through training organized for the study participants. The training was preceded and followed by the cognitive functioning measurement.

The subjects from both study groups participated in eight training sessions, two per each week. Each session provided training with two software modules aimed to stimulate different cognitive functions in the following pairs: (a) memory and attention; (b) language and visuospatial processing. As a result, each module involved four training sessions. A single session lasted 45 minutes to one hour, depending on the pace of work of individual participants. In every training session subjects were accompanied by a training assistant - a trained person who provided explanations or guidance if necessary.

For each cognitive function, the study participants started the first session at the first, lowest difficulty level. The highest possible difficulty level to achieve was level 3. The participant moved to a higher level having reached 75% accuracy in the previous training session. In the case of accuracy falling below 50%, the participant returned to the lower level of the game.

Before starting the training programme and after its completion, the study participants' cognitive functioning was evaluated.

Participants

The study was conducted in Poland. All participants were Polish citizens for whom Polish was a native language. The initial study sample consisted of 150 individuals, including 75 patients with mild dementia (Mini Mental State Examination: 19 – 23 points) aged 60-89 recruited from patients of a geriatric clinic, from patients of a healthcare facility of the „Nowa Wspolna Droga" Association in Gniezno and through advertisement, and 75 volunteers aged 60-88 without cognitive impairments (Mini Mental State Examination: 28 – 30 points) recruited through advertisement. The inclusion criteria for the sample also included a lack of mental disorders and serious somatic illnesses, as well as visual, auditory and motor impairments preventing the use of the game peripherals. All subjects signed informed consent forms to participate in the study. In the case of individuals with cognitive impairment consent was also obtained from their actual caregivers. The data from two measurements collected prior to the training and after the training were obtained from 27 older adults with mild dementia and 72 non-demented older adults. Those individuals were included in the final sample described below in Table 2. A significant loss from the group of subjects with mild dementia resulted from difficulties faced during training, their need to be accompanied by caregivers who often showed lack of time and tiredness of study procedure leading to its discontinuation.

The study was conducted in the Institute of Psychology at the Kazimierz Wielki University in Bydgoszcz, and in the Departments of Geriatrics and Psychiatry at the Nicolaus Copernicus University in Torun, Collegium Medicum in Bydgoszcz as well as in a healthcare facility of the „Nowa Wspolna Droga" Association in Gniezno.

Intervention

The work on the development of the GRADYS game can be described based on the scheme of technology development and evaluation process (1). This scheme describes a sequence of activities that starts with the research on the needs assessment of the intended users of a given technology, and continues in two phases, the lab phase and the field phase.

The starting point for the work on the GRADYS game was to identify the needs of the end user and the nature of CT to be implemented in the game. The above-mentioned cognitive decline observed in the ageing process, supported by numerous research findings, provides objective evidence that CT is a significant and positive intervention targeted at older adults. Based on the current literature on cognitive ageing the game was decided to engage four main cognitive functions: two that show pronounced deterioration with age even in the absence of dementia (and in the case of dementia even more pronounced), i.e. memory and attention, and two that deteriorate less seriously in normal ageing but significantly in the course of dementia, namely language and visual-spatial function.

The perceived need in older adults to improve their cognitive function was confirmed in meetings with people from this age group, at Universities of the Third Age among others and at various institutions for seniors. Given the characteristics of the target group, the tasks for the game then developed were to simulate cognitive functions while maintaining the users' physical comfort and mental welfare as well as their interest and motivation to use the game. In order to realize those tasks, it was assumed that GRADYS shall meet the following criteria.

- The exercises that engage cognitive functions shall be embedded in the context of real-life places, situations and every-day activities of seniors living in Poland for the scenario to be perceived as natural and familiar to the user.
- The game environment shall reflect the natural environment, yet it shall not be too rich as not to provide undue stimulation that is beyond the attention and perception capacity of the end user.
- The game shall enable the user to play at increasingly higher and more difficult levels and the players shall be informed about their results and progress made in the game to induce and maintain their motivation to play the game.
- The game shall be played while seated to ensure the user's physical comfort and safety since VR setting prevents visual control of the surroundings.
- It is necessary for a simultaneous use of game devices, including VR and standard visual and auditory correction devices that are often indispensable for older adults.
- The VR devices shall be relatively easy to use so that they do not pose an additional challenge for or build resistance and fear in the end users.
- The users shall be able to play the game on their own without the assistance of an instructor or any trained person for the end product to be used by older adults in their homes.
- The game as a whole (both software and hardware) shall use such solutions that will make the end product affordable for institutions working with seniors in Poland, and possibly – also for individual users, being private persons.

The subsequent phases of game development in the context of the concerned scheme of technology development and evaluation process involved laboratory work and have been described in Table 2.

The final result of laboratory work was the GRADYS game which is a CT with VR elements for cognitive enhancement in older adults. The efficacy of this game as a CT was tested in the research.

There are four modules in the game dedicated to the four areas of cognitive functioning: (1) attention; (2) memory; (3) language; (4) visuospatial processing. The storyline of each module scenario consists in several tasks that create a consistent story line inspired by daily life events. For every cognitive module there are two possible scenarios, of which one is set at home and the other takes place outside the home environment. There are three difficulty levels for each module and location. The game software also includes a tutorial that helps users learn the ways to navigate the game and allows them to practice.

The player moves in the game environment and interacts with it from the first-person perspective (FPP). The game is controlled with the Oculus Rift DK2 and the Xbox 6DOF control pad. For detailed characteristics of the GRADYS game see different article (72).

Outcome measures

Two sets of research tools were used: screening tests that help select subjects for the study sample and tools that evaluate cognitive functioning before starting the training with the GRADYS game (pretest) and following its completion (posttest).

The following research tools were used in the study:

1. Screening tests:

- Structured interview – for the assessment of inclusion criteria and sociodemographic variables;
- Mini Mental State Examination (MMSE) – for the classifications to two research groups: non-demented older adults and older adults with mild dementia, according to the cognitive functioning;
- Addenbrooke Cognitive Examination III (ACE – III) – for the assessment of cognitive functioning in addition to MMSE.

1. Tools to measure cognitive abilities according to four modules (pretest and posttest):

- Module 1. Memory: Digit Span test contained in WAIS – R (PL), Benton Visual Retention Test (BVRT), Rey Auditory Verbal Learning Test (AVLT), Famous Faces Test, Rey-Osterrieth complex figure test (ROCF) – delayed reproduction;
- Module 2. Attention: Digit Symbol test contained in WAIS – R (PL); Colour trial test (CTT) – Adult version, d2 Test of Attention (including following performance indices: WZ – speed of processing, %B – percentage of errors, WZ-B – error corrected speed of processing, ZK – ability to concentrate);

- Module 3. Visuospatial abilities: a block design test contained in WAIS – R (PL), Rey-Osterrieth complex figure test (ROCF) – direct copying.
- Module 4. Language abilities: Verbal fluency test (from ACE – III); Boston Naming Test (BNT);

Data analysis

The comparison of baseline cognitive performance in non-demented older adults and older adults with mild dementia was made using the Hotelling T^2 test – for cognitive performance in general and the Student's *t* test – for the results of particular cognitive measures. In the case that homogeneity of variance was violated, the Welch's t test was used. The t test was also supplemented by the non-parametric Mann-Whitney *U* test due to unequal number of participants in both groups.

In order to evaluate the progress made by the subjects throughout the training, we compared difficulty levels reached by the subjects in each module separately within each group: older adults without cognitive impairment and older adults with mild dementia. For this purpose, with regard to the ordinal character of the dependent variable, the non-parametric Friedman test was used. Inter-group comparisons of the training progress was carried out for the last, fourth session within each cognitive module with the use of the Mann-Whitney U test.

The evaluation of change in each cognitive ability that occurred due to training measured by means of other than training-related tasks, including a comparison between the study groups of non-demented older adults and older adults with mild dementia was carried out with the use of the repeated measures multivariate analysis of variance (RM MANOVA) with group as a between-subject variable. Due to disproportion in the sizes of both groups, RM MANOVA was conducted also in the two groups separately. RM MANOVA in both groups was supplemented by one-way tests for particular outcome measures.

Finally, to compare participants who achieved different levels of difficulty at the end of the training in terms of the changes of cognitive tests performance the Kruskal-Wallis test or the Mann-Whitney *U* test were used (depending on the number of groups being compared) separately in both groups. All statistical analyses were conducted in Statistica 13.

Results

Baseline cognitive performance. As expected, statistical analyses indicated better baseline cognitive performance in the group of non-demented older adults in general (Hotelling T^2 = 130.868; $p < .001$) and in the majority of pretest cognitive measures (Table 3). In a few of cognitive measures, there was no significant differences between groups (Table 3). All these cognitive measures was relatively easy. Surprisingly, two performance indices in the sustained attention task (d2) were significantly better in the group of older adults with dementia in comparison to participants without cognitive impairment (Table 3). However, the WZ-B indicator is vulnerable to overestimation due to the skipping a part of the characters in the row. Therefore, the high WZ indicator can be an artefact resulting from the fact that participants with mild dementia often acted contrary to instructions of d2 test to follow the letters in a row one by one and moved immediately to further letters. The value of the next indicator higher in the group with dementia, i.e. WZ-B, can be a derivative of WZ value.

The progress throughout the training. Both groups demonstrated progress throughout the training: older adults without cognitive impairment and older adults with mild dementia (Table 4, the Friedman's test; Figure 2). Yet the group of non-demented older adults showed greater progress for the majority of cognitive modules except the attention module, in which the difference between the groups in the last training session was not statistically significant (Table 4, the Mann-Whitney U test). At the same time, the mean and the median values of the difficulty levels achieved by the participants in consecutive training sessions, as well as the percentage of participants who achieved particular levels of difficulty in subsequent sessions of a given module indicated uneven difficulty of the cognitive modules. The memory module was found to be most difficult for the study participants, while the attention module was the easiest one.

Changes in cognitive functioning under the influence of training with the GRADYS game. RM MANOVA with group as a between-subject variable showed two significant effects (Table 5). Firstly, the groups of older adults without cognitive impairment and older adults with mild dementia differed significantly as regards the level of cognitive functioning. Secondly, there was also significant differences in cognitive functioning before the training with the use of the GRADYS game and after its completion.

As regards the interaction effect, it is not significant yet the probability value (p = .073) was only slightly above the assumed value of statistical significance with α = .05. While partial eta squared for the interaction effect was 0.348 which means a large effect size (73). This finding is sufficient to justify further analysis that help to isolate exactly where are the significant means differences. Obtained effect size suggested that the group may be a factor moderating the effect of training with regard at least to a part of applied measures of cognitive abilities.

According to RM MANOVA computed for each group separately, significant changes occurred only in older adults without cognitive impairment (Table 6). However, in the group of older adults with mild dementia the observed power was low, in turn the effect size was big. It suggest that the statistical power of conducted test was insufficient to estimate the cognitive changes after the training in the population of older adults with mild dementia. The reason probably was, at least partially, too small sample size and high sampling error.

In turn, one-way tests for the differences between pretest and posttest for particular cognitive measures computed in both groups indicated some significant changes in the group of older adults with mild dementia, however much less than in the group of non-demented participants (Table 7). Cognitive domains for which the improvement proved to be most pronounced were attention and visuospatial processing.

With regard to attention, its measures improved after the training mainly in the group older adults without cognitive impairment. This applied to all d2 test's indicators and to the shortening of the time of CTT-2 test performance. Whereas in the group of older adults with mild dementia, post-training significant changes revealed only in one indicator from a fairly easy d2 test. The percentage of errors in d2 test decreased significantly.

Among the visuospatial measures in non-demented older adults, the performance of Block Design from WAIS - R (PL) improved significantly, while the correctness of the direct ROCF copy improved in older adults with mild dementia. It can be noted that after training, the cognitively not impaired participants improved performance of more demanding cognitive tasks, while individuals with mild dementia – of the easier ones.

Regarding memory, improvement was noted only in three indicators and only in the group of older adults without cognitive impairment. These indicators were: backward Digit span from WAIS - R (PL), delayed recall of ROCF and error indicator from BVRT. In turn, the indicator of correct responses in BVRT has deteriorated in persons with mild dementia.

There was no improvement in performance on the measures of language abilities – the verbal fluency test or the Boston Naming Test.

The relationship between the progression in the training and the improvement of cognitive performance beyond the game environment. The comparison between participants who differ in final levels of difficulty achieved in particular game modules indicated no relationship between the training progress in a given cognitive module and improvement in cognitive functioning corresponding to it (Tables 8 and 9). These comparisons were conducted separately in non-demented older adults and older adults with mild dementia. In some cases, three groups were compared, corresponding to three levels of difficulty that could be achieved in the last training session (Table 8). Ultimately, in some cases only two groups were compared, as in cases where very few participants remained at the lowest level of difficulty at the end of the training (level 1), this subgroup was combined with participants that have reached level 2 (Table 9). This was only the case for the older adults without cognitive impairment. No comparison of the training achievements in the attention module was made because almost all participants finished this module at the maximum difficulty level. It was 67 participants form a 72-strong group of non-demented older adults (96%) and 23 participants from a group of 27 older adults with mild dementia (85%).

Discussion

The aim of the research discussed in the present paper was to evaluate the efficacy of the cognitive training using the game with elements of VR in the target group of people aged 60 and above without cognitive impairments and with mild dementia.

The study leads to the general conclusion that the GRADYS game can be used by non-demented older adults. Whereas the usefulness of the GRADYS game for people with mild dementia is questionable and at this point we cannot recommend our software for this group.

Participants with mild dementia before the start of the training were worse in cognitive tasks than non-demented older adults, which is a rather obvious result. Nevertheless, subjects from both groups showed progress in the course of training within all cognitive modules included in the software. The progress was indicated by increasingly higher difficulty levels reached by the players in subsequent training sessions. One can therefore conclude that the proposed solution is learnable and effective when it comes to improving on the performance of the trained cognitive tasks for all participants of the study. However, among older adults with mild dementia not only less progress in the training, but also a large loss of participants from the sample was observed. Many subjects from the group of adults with mild dementia selected for the study withdrew from participation during the training process, some of them in view of major difficulties involved in its completion, including difficulties involved in controlling the game and inability to concentrate on cognitive tasks due to an excessive cognitive burden in using new technology (getting their bearings in VR, using controllers). In those cases, low learnability caused lack of acceptability of the GRADYS game, which in turn contributes to decreased efficiency of this game in older adults with mild dementia.

As regards effectiveness in enhancing cognitive functions beyond the tasks trained in the game environment (i.e. transfer), a significant difference in cognitive tests performance before and after training indicated in RM MANOVA proves a positive impact of the training. At the same time, one-way tests computed for particular outcome measures separately in both groups revealed that positive changes in the performance of cognitive tasks are observed almost exclusively in non-demented older adults.

In the case of older adults without cognitive impairments, we can speak about overall enhancement of attention indicators. In this group also improved: visuospatial processing (although only two its indicators were taken into account in the study), visual aspects of memory and working memory, but not verbal learning and language.

The situation is quite different among older adults with mild dementia. Positive changes in this group are observed only in the percentage of errors in d2 test and in the copy of Rey-Osterrieth complex figure which belong to the easiest tasks in the whole set of cognitive measures used in this research. Moreover, in this group in the assessment after training increases the number of errors in BVRT.

Poor training effects in participants with mild dementia, despite its higher effectiveness in non-demented older adults are consistent with the results of previous studies, which prove that in individuals with dementia CS or perhaps CR work better than CT (22, 25, 29, 30, 31, 32). At the same time, research shows that in the case of MCI, the situation is reversed and CT is more effective than CS (31). Moreover, in persons with MCI CT leads to better effects than in those with dementia (40) and can even retain the effectiveness comparable to those observed in older adults without cognitive impairment (20). Since the CT using GRADYS game showed sufficient learnability for non-demented older adults and some older adults with mild dementia, it can be assumed that it may also be used by individuals with MCI. This hypothesis would require an empirical verification, however, the results of previous research encourage testing the effectiveness of the GRADYS game in MCI patients.

Other conclusion regards possibilities to enhance the game through making the game control more natural and easier by, for example, replacing the control pad with a haptic glove for VR. Thanks to such improvements the game may become useful also for older adults with mild dementia.

Finally, in the light of the research results, changes in the performance of cognitive tasks beyond the game environment are not related to the results of the training itself, contrary to what was expected. Although significant changes after the training occurred only in some outcome cognitive measures, what made difficult to observe their relation with the progress in training, however even statistical significant improvement in cognitive tests was not associated with the progress in training modules. It should be noted that it is still do not known what is the mechanism underlying such hypothetical relationship – would it be the progress level or pace or difficulty level of tasks. Perhaps it is also possible to improve cognitive functioning regardless of the progress in training, as a consequence of cognitive activation itself. This would require further investigation.

Our study bears several shortcomings which may give directions for further studies. First of all, an quasi-experimental uncontrolled pretest-posttest design was applied. The lack of a control group makes it impossible to differentiate the training-related effect from the effect of repeated measurement and practice effect. Simultaneously, in order to reduce the probability of the practice effect occurrence for the majority of cognitive measures applied in pretest and posttest, different versions of the test were used (except for those, where no such versions exist). In addition, because the improvement occurred for some cognitive measures using different versions in the pretest and posttest, and at the same time the improvement did not occur for some measures using the same versions in the pretest and posttest, the observed improvement cannot be attributed to the simple practice effect. However, further development of the GRADYS game will definitely require conducting a study on its effectiveness in enhancing cognitive functions of older adults, including control groups – a passive and active one.

The shortcoming of our research was also design a game control system too difficult for participants with mild dementia causing them to withdraw from training.

The limitations also include the unequal number of neuropsychological measures of particular cognitive functions with fewer indicators for language and visuospatial functions.

Conclusions

The GRADYS game can be useful in cognitive training in non-demented older adults. The hypothesis that it can also be used in older adults with MCI needs to be tested. Currently, we cannot recommend the GRADYS game for use in persons with dementia, but maybe it will be possible after the adaptation of software and hardware of the game. The rapid development of modern technologies creates opportunities for improving current conceptual solutions, software and hardware with regard to the game natural feel, intuitive simplicity and comfort, as well as its affordability for institutions working with seniors and individual users.

Abbreviations

ACE-III – Addenbrooke Cognitive Examination III

AD – Alzheimer’s disease

AVLT – Rey Auditory Verbal Learning Test

BVRT – Benton Visual Retention Test

CCT – computerized cognitive training

CI – cognitive interventions

CR – cognitive rehabilitation

CS – cognitive stimulation

CT – cognitive training

CTT – Colour trial test

FPP – first-person perspective

HMD – head-mounted display

MCI – mild cognitive impairment

MMSE – Mini Mental State Examination

RM MANOVA – repeated measures multivariate analysis of variance

ROCF – Rey-Osterrieth complex figure test

UFOV – Useful Field of View

VG – video games

VR – virtual reality

WAIS – R (PL) – Wechsler Adult Intelligence Scale – Revised (Polish)

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study protocol and the informed consent form was approved by the Bioethics Committee of the Nicolaus Copernicus University in Toruń functioning at Collegium Medicum in Bydgoszcz which acts pursuant to the regulation of the Minister of Health and Welfare of May 11, 1999 on detailed rules for the creation, financing and functioning of bioethics committees (Dz. U. [Journal of Laws] No 47, item 480).

Informed consent was obtained from all individual participants included in the study. All subjects gave written informed consent in accordance with the Declaration of Helsinki. If the participants with mild dementia had a legal guardian, the legal guardian gave written informed consent in accordance with the Declaration of Helsinki.

This article does not contain any studies with animals performed by any of the authors.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

LZL, MWD and PI contributed conception and design of the study; AW designed the technological aspects of GRADYS game and supervised the software development; LZL organized the database; LZL performed the statistical analysis; LZL, MWD and PI interpreted the results of statistical analysis; LZL wrote the first draft of the manuscript; LZL, MWD and PI wrote sections of the manuscript. KKK and AA coordinated and supervised data acquisition in patients with mild dementia. LZL, MWD and PI coordinated and supervised data acquisition in healthy older adults. MP, APS, ŁW, LZL and MWD contributed data acquisition. All authors contributed to manuscript revision, read and approved the submitted version.

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Tables

Table 1

	Non-demented older adults (n = 72, 54 women)		Older adults with mild dementia (n = 27, 22 women)	
	M	*SD*	*M*	*SD*
Age	67.861	5.829	72.037	7.434
Yeas of education	13.606	3.864	12.577	3.325
MMSE	28.694	1.217	22.33	1.209
ACE – III	91.139	6.374	75.667	14.959

Table 2

GRADYS game development and evaluation process in the laboratory phase, based on the scheme proposed by Schulz et al. (2015)

Steps/Stages (in Lab)	Activity/Work	Methods
User-centred design prototype	Designing gameplay scenarios and cognitive tasks involved therein. Designing the game interface and solutions for the mechanism underlying interaction with the game, the navigation mechanisms, the rules of promotion to the next level in the game and how to communicate with a player and inform them about their results. Planning on a set of technical solutions necessary to navigate the game.	Storyboarding; Individual in-depth interviews; Focus group.
Robust prototype	Programming the game while taking into account all the aspects mentioned above, selecting graphic environment and the assets. Testing the game software and solutions applied therein as well as technical solutions and devices used.	Laboratory testing Scenario testing; Observation of task performing (by the team members).
Laboratory prototype	Testing the target set of software and hardware, including final game scenario as well as the mechanisms for interaction between player and game and navigation mechanisms with regard to their user-friendliness, intuitive simplicity, and learnability.	Observation of task performing (by the targeted end users and the team members); ”Think aloud” (by the targeted end users); Focus group.

Table 3

A comparison of baseline cognitive performance in groups of non-demented older adults and older adults with mild dementia: the Student's t test and the Mann-Whitney U test[a]

Cognitive measures	The Student's *t* test/ the Welch's *t* test[b]			The Mann-Whitney *U* test	
	t[b]	*p*	Hedges's *g*	*Z* corr.[c]	*p*
Digit Symbol WAIS – R (PL)	2.899	.005	0.65	2.748	.006
CTT-1 time	-2.301[d]	.029	0.76	-2.986	.003
CTT-1 errors	-1.185[d]	.244	0.32	-1.427	.153
CTT-2 time	-2.361[d]	.025	0.71	-3.041	.002
CTT-2 errors	-1.457[d]	.156	0.45	-2.178	.029
d2 WZ	-2.848	.005	0.68	-2.829	.005
d2 %B	1.021[d]	.474	0.16	-0.519	.604
d2 WZ-B	-2.396	.019	0.54	-2.675	.007
d2 ZK	1.014	.310	0.23	1.226	.220
Block Design WAIS – R (PL)	3.018	.003	0.68	2.426	.015
ROCF copy	2.332[d]	.026	0.63	2.759	.006
ROCF delayed recall	3.727	<.001	0.83	3.502	<.001
Digit span – forward WAIS – R (PL)	0.255	.799	0.06	0.619	.536
Digit span – backward WAIS – R (PL)	2.683	.009	0.60	2.426	.015
AVLT list A, trial 1	2.579	.011	0.58	2.319	.020
AVLT list A, trial 5	5.528	<.001	1.24	4.558	<.001
AVLT list B	3.324[d]	.001	0.57	3.042	.002
AVLT list A, trial 6	4.414	<.001	0.99	3.949	<.001
AVLT list A, trial 7	4.961	<.001	1.11	4.206	<.001
AVLT list A, recognition	0.221[d]	.827	0.07	1.729	.084
BVRT correct reproductions indicator	3.333	.001	0.75	2.873	.004
BVRT errors indicator	-3.642[d]	<.001	0.95	-3.398	<.001
Famous Faces Test	4.778[d]	<.001	1.28	4.713	<.001
Verbal Fluency (ACE-III)	3.967	<.001	0.89	3.192	.001
Boston Naming Test	2.163[d]	.038	0.63	1.958	.050

Note:

[a] The means and standard deviations for all above mentioned cognitive measures in both research groups are presented in Table 7 which contains the means and standard deviations for both groups in pretest and posttest

[b] If the Levene's test indicated the unequality of variances, the Welch's *t* test was calculated.

[c] Correction for ties in the ranking.

[d] The Welch's *t* test.

Table 4

A comparison of difficulty levels achieved in subsequent training sessions for each cognitive module in the groups of non-demented older adults and older adults with mild dementia (the Friedman's test) and a comparison of the groups as regards their ultimate difficulty level (Session 4) achieved in individual cognitive modules (the Mann-Whitney U test)

	Training Sessions											
	Session 1		Session 2		Session 3		Session 4		Friedman's test		Mann-Whitney test (Session 4)	
	M (SD)	*Me*	*M (SD)*	*Me*	*M (SD)*	*Me*	*M (SD)*	*Me*	*Chi-squared ANOVA*	*p* level	*Z* test	*p* level
Memory												
OA-ND[a]	1.000 (0.000)	1	1.500 (0.504)	1.5	2.133 (0.851)	2	2.484 (0.763)	3	124.347	$p < .001$	3.045	.002
OA-MD[b]	1.000 (0.000)	1	1.318 (0.477)	1	1.636 (0.727)	1	1.955 (0.899)	2	28.982	$p < .001$		
Attention												
OA-ND	1.000 (0.000)	1	1.906 (0.294)	2	2.813 (0.432)	3	2.953 (0.213)	3	180.204	$p < .001$	1.931	.053
OA-MD	1.000 (0.000)	1	1.708 (0.464)	2	2.542 (0.721)	3	2.792 (0.509)	3	62.445	$p < .001$		
Visuospatial processing												
OA-ND	1.000 (0.000)	1	1.703 (0.460)	2	2.250 (0.642)	2	2.563 (0.588)	3	149.922	$p < .001$	3.784	$p < .001$
OA-MD	1.000 (0.000)	1	1.500 (0.511)	2	1.750 (0.676)	2	1.875 (0.797)	2	33.756	$p < .001$		
Language												
OA-ND	1.000 (0.000)	1	1.683 (0.469)	2	2.317 (0.748)	2	2.600 (0.588)	3	140.177	$p < .001$	2.737	.006
OA-MD	1.000 (0.000)	1	1.318 (0.477)	1	1.682 (0.646)	2	2.136 (0.710)	2	39.604	$p < .001$		

Note:[a]OA-ND – Non-demented older adults; [b]OA-MD – Older adults with mild dementia

Table 5

Changes in cognitive functioning under the influence of training with the GRADYS game in the groups of non-demented older adults and older adults with mild dementia: RM MANOVA with a qualitative predictor[a]

Effect		Value	*F*	*p* level	*Partial Eta Squared*	*Observed power*
Intercept	Wilks' Lambda	0.001	2307.172	$p < .001$	0.999	1.000
	Pillai's Trace	0.999	2307.172	$p < .001$	0.999	1.000
	Hotelling's Trace	790.127	2307.172	$p < .001$	0.999	1.000
	Roy Largest Root	790.127	2307.172	$p < .001$	0.999	1.000
Group	Wilks' Lambda	0.471	3.285	$p < .001$	0.529	1.000
	Pillai's Trace	0.529	3.285	$p < .001$	0.529	1.000
	Hotelling's Trace	1.125	3.285	$p < .001$	0.529	1.000
	Roy Largest Root	1.125	3.285	$p < .001$	0.529	1.000
Training	Wilks' Lambda	0.613	1.840	.023	0.387	0.969
	Pillai's Trace	0.387	1.840	.023	0.387	0.969
	Hotelling's Trace	0.630	1.840	.023	0.387	0.969
	Roy Largest Root	0.630	1.840	.023	0.387	0.969
Training*Group	Wilks' Lambda	0.652	1.562	.073	0.349	0.930
	Pillai's Trace	0.349	1.562	.073	0.349	0.930
	Hotelling's Trace	0.535	1.562	.073	0.349	0.930
	Roy Largest Root	0.535	1.562	.073	0.348	0.930

Note:

[a] Design: Intercept + group, Within Subject Design: training (pretest vs. posttest)

Table 6

Changes in cognitive functioning under the influence of training with the GRADYS game: RM MANOVA computed separately in two research groups: non-demented older adults and older adults with mild dementia

Group	Effect		Value	*F*	*p* level	*Partial Eta Squared*	*Observed power*
OA-ND[a]	Intercept	Wilks' Lambda	0.001	3078.744	$p <$ .001	0.999	1.000
		Pillai's Trace	0.999	3078.744	$p <$ .001	0.999	1.000
		Hotelling's Trace	1637.630	3078.744	$p <$ .001	0.999	1.000
		Roy Largest Root	1637.630	3078.744	$p <$ .001	0.999	1.000
	Training	Wilks' Lambda	0.326	3.879	$p <$ .001	0.674	1.000
		Pillai's Trace	0.674	3.879	$p <$ .001	0.674	1.000
		Hotelling's Trace	2.063	3.879	$p <$ .001	0.674	1.000
		Roy Largest Root	2.063	3.879	$p <$ .001	0.674	1.000
OA-MD[a]	Intercept	Wilks' Lambda	0.000	336.666	.003	1.000	0.969
		Pillai's Trace	1.000	336.666	.003	1.000	0.969
		Hotelling's Trace	4208.325	336.666	.003	1.000	0.969
		Roy Largest Root	4208.325	336.666	.003	1.000	0.969
	Training	Wilks' Lambda	0.652	1.562	.242	0.978	0.208
		Pillai's Trace	0.349	1.562	.242	0.978	0.208
		Hotelling's Trace	0.535	1.562	.242	0.978	0.208
		Roy Largest Root	0.535	1.562	.242	0.978	0.208

Note:

[a] OA-ND – non-demented older adults; OA-MD – older adults with mild dementia

Table 7

The differences between pretest and posttest for particular cognitive measures in the groups of non-demented older adults and older adults with mild dementia. One-way tests computed separately in both groups

Cognitive measures	Groups	Pretest *M* *(SD)*	Posttest *M* *(SD)*	Fisher's *F*	*p* value	*Partial eta squared*
Digit Symbol WAIS – R (PL)	OA-ND[a]	39.917 (13.883)	41.859 (10.801)	3.450	.067	0.046
	OA-MD[b]	30.962 (13.347)	32.067 (13.904)	1.183	.286	0.044
CTT-1 time	OA-ND	67.389 (27.690)	61.930 (22.843)	2.952	.090	0.040
	OA-MD	105.667 (84.748)	88.080 (40.528)	1.318	.261	0.048
CTT-1 errors	OA-ND	0.097 (0.342)	0.028 (0.166)	2.816	.098	0.038
	OA-MD	0.222 (0.506)	0.040 (0.192)	2.933	.099	0.101
CTT-2 time	OA-ND	130.014 (51.600)	120.761 (45.302)	5.167	**.026**	0.068
	OA-MD	180.815 (107.236)	193.960 (122.325)	1.670	.208	0.060
CTT-2 errors	OA-ND	0.222 (0.717)	0.211 (0.579)	0.017	.898	0.0002
	OA-MD	0.704 (1.660)	0.520 (1.244)	0.896	.352	0.033
d2 WZ	OA-ND	316.493 (125.297)	350.901 (143.112)	18.287	***p* < .001**	0.205
	OA-MD	392.958 (99.711)	387.318 (118.466)	0.162	.691	0.006
d2 %B	OA-ND	23.870 (34.578)	15.273 (14.907)	5.838	**.018**	0.076
	OA-MD	18.945 (13.410)	16.299 (11.794)	4.364	**.047**	0.144
d2 WZ-B	OA-ND	256.155 (126.183)	300.167 (134.440)	42.946	***p* < .001**	0.377
	OA-MD	320.708 (98.540)	328.00 (116.011)	0.382	.542	0.014
d2 ZK	OA-ND	111.329 (47.701)	129.690 (50.946)	14.674	***p* < .001**	0.171
	OA-MD	100.375 (48.374)	105.903 (48.714)	1.005	.325	0.047
Block Design WAIS – R (PL)	OA-ND	21.833 (8.454)	24.183 (8.118)	12.509	***p* < .001**	0.150
	OA-MD	15.852 (9.623)	17.017 (9.433)	2.433	.131	0.086
ROCF copy	OA-ND	33.028 (4.663)	33.809 (2.893)	1.804	.184	0.025
	OA-MD	29.596 (7.094)	32.562 (4.878)	8.867	**.006**	0.254
ROCF delayed recall	OA-ND	19.146 (8.329)	21.735 (7.233)	9.795	**.003**	0.121
	OA-MD	12.481 (6.693)	12.945 (6.811)	0.216	.646	0.008
Digit span – forward	OA-ND	5.693 (1.931)	5.704 (1.731)	0.210	.648	0.003

WAIS – R (PL)	OA-MD	5.519 (2.471)	5.269 (2.176)	0.651	.427	0.024
Digit span – backward	OA-ND	5.042 (1.699)	5.479 (1.635)	6.619	**.012**	0.085
WAIS – R (PL)	OA-MD	3.963 (1.190)	3.769 (1.219)	0.435	.515	0.016
AVLT list A, trial 1	OA-ND	5.268 (1.784)	5.409 (1.553)	0.353	.555	0.005
	OA-MD	4.259 (1.583)	4.346 (1.413)	0.089	.767	0.003
AVLT list A, trial 5	OA-ND	11.437 (2.354)	11.310 (2.481)	0.268	.606	0.004
	OA-MD	8.407 (2.620)	8.692 (2.126)	0.694	.412	0.026
AVLT list B	OA-ND	5.113 (2.140)	4.634 (2.050)	2.848	.096	0.039
	OA-MD	4.000 (1.144)	3.962 (1.285)	0.027	.871	0.001
AVLT list A, trial 6	OA-ND	9.070 (3.069)	9.366 (3.181)	0.894	.348	0.012
	OA-MD	6.037 (2.981)	6.500 (3.153)	0.623	.437	0.023
AVLT list A, trial 7	OA-ND	9.254 (3.066)	8.873 (3.801)	1.036	.312	0.014
	OA-MD	5.704 (3.440)	6.154 (3.371)	1.013	.323	0.038
AVLT list A, recognition	OA-ND	14.056 (1.727)	14.056 (1.694)	0.000	1.000	0.000
	OA-MD	13.852 (4.688)	13.360 (4.419)	0.272	.607	0.010
BVRT correct reproductions indicator	OA-ND	5.889 (1.781)	6.189 (1.962)	2.457	.121	0.033
	OA-MD	4.444 (2.259)	3.692 (1.957)	5.170	**.031**	0.166
BVRT errors indicator	OA-ND	6.292 (3.009)	5.455 (3.125)	7.234	**.009**	0.092
	OA-MD	9.519 (4.219)	9.885 (4.585)	0.221	.643	0.008
Famous Faces Test	OA-ND	9.583 (1.432)	9.471 (1.774)	0.544	.463	0.008
	OA-MD	7.444 (2.154)	7.600 (2.465)	0.154	.698	0.006
Verbal Fluency (ACE-III)	OA-ND	10.958 (2.236)	11.343 (2.426)	2.576	.113	0.035
	OA-MD	8.778 (2.913)	8.630 (3.628)	0.070	.794	0.003
Boston Naming Test	OA-ND	57.722 (3.027)	58.000 (2.974)	1.710	.195	0.024
	OA-MD	55.259 (5.620)	55.577 (5.500)	0.513	.480	0.019

Note:

[a] OA-ND – non-demented older adults; [b] OA-MD – older adults with mild dementia

Table 8

A comparison of the cognitive measures changes (the posttest minus the pretest scores) in participants achieving different difficulty levels at the end of the training sessions in corresponding module, separate *analysis in the groups of non-demented older adults and older adults with mild dementia (the Kruskal-Wallis test)*

	Groups which achieved different final levels of difficulty in the training										
	Level 3[a]			Level 2[a]			Level 1[a]			Kruskal-Wallis test	
	N	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*H*	*p* level
Memory											
OA-ND[b]	48			14			10				
Digit span – forward WAIS – R (PL)		0.121	1.340		-0.538	0.967		0.500	0.527	5.854	.054
Digit span – backward WAIS – R (PL)		0.585	1.440		0.000	1.291		0.300	1.636	2.056	.358
AVLT list A, trial 1		-0.013	2.216		0.538	1.506		0.773	1.337	0.716	.699
AVLT list A, trial 5		-0.376	2.009		0.538	2.222		-0.044	2.171	1.951	.377
AVLT list B		-0.306	2.095		-0.692	2.213		-0.911	2.321	1.203	.548
AVLT list A, trial 6		0.093	2.785		1.231	2.833		0.393	1.724	1.608	.448
AVLT list A, trial 7		-0.194	2.928		0.769	1.691		-2.725	4.839	3.980	.137
AVLT list A, recognition		-0.297	2.020		0.385	2.256		0.394	1.724	1.946	.378
BVRT correct reproductions indicator		0.260	1.503		0.154	2.154		0.900	1.792	2.816	.245
BVRT errors indicator[d]		-1.026	2.474		-0.462	3.282		-1.000	2.625	1.666	.435
Famous Faces Test		0.041	1.069		0.077	1.038		-0.600	2.011	0.268	.875
ROCF deleyed recall[d]		3.047	7.813		2.423	6.931		0.600	2.654	1.081	.582
OA-MD[c]	9			7			11				
Digit span – forward WAIS – R (PL)		-0.667	1.581		0.000	1.095		-0.091	1.973	0.814	.666
Digit span – backward WAIS – R (PL)		-0.667	1.225		0.333	1.366		0.091	1.758	2.313	.315
AVLT list A, trial 1		-0.222	1.202		0.333	0.816		0.000	1.949	0.911	.634
AVLT list A, trial 5		-0.222	1.986		1.000	1.414		0.091	1.700	1.573	.455
AVLT list B		-0.667	1.000		0.333	1.033		0.091	1.300	3.976	.137
AVLT list A, trial 6		-0.111	2.028		2.500	4.087		-0.455	2.806	2.893	.235
AVLT list A, trial 7		0.111	2.147		0.333	1.033		0.273	2.533	0.343	.842
AVLT list A, recognition		-0.111	2.167		0.833	1.722		-1.455	7.815	0.812	.667
BVRT correct reproductions		-	1.269		-	1.789		0.000	1.844	3.723	.156

indicator[d]		1.256			1.000						
BVRT errors indicator		1.098	1.850		1.167	4.167		0.545	3.532	0.289	.865
Famous Faces Test		0.778	1.787		0.000	0.632		-0.400	2.713	2.212	.331
ROCF deleyed recall		2.667	3.824		-0.083	2.498		-0.412	6.729	1.852	.396
Visuospatial processing											
OA-MD	8			10			9				
Block Design WAIS – R (PL)		0.750	3.918		2.000	4.243		-0.333	1.803	2.317	.314
ROCF copy[d]		0.563	4.118		4.222	4.251		4.552	6.223	4.020	.134
Language											
OA-MD	10			12			5				
Verbal fluency (ACE III)		0.667	2.693		-0.417	3.343		0.250	1.708	0.340	.844
Boston Naming Test		-0.222	1.563		0.333	2.498		1.250	2.217	1.243	.537

Note:

[a]The difficulty increases from level 1 (the easiest one) to level 3 (the most difficult one)

[b]OA-ND – Non-demented older adults

[c]OA-MD – Older adults with mild dementia

[d]Outcome measures for which significant differences between pretest and posttest were noted

Table 9

A comparison of the cognitive measures changes (the posttest minus the pretest scores) in non-demented older adults ending training at the maximum difficulty level in corresponding module or below (the Mann-Whitney U test)

	Groups which achieved different final levels of difficulty in the training							
	Level 3[a]			Level 2 and 1[a]			Mann-Whitney test	
	N	*M*	*SD*	*N*	*M*	*SD*	*Z*	*p* level
Visuospatial processing								
OA-ND[b]	44			28				
Block Design WAIS – R (PL)		1.423	6.243		3.731	4.396	- 1.303	.193
ROCF copy[c]		0.975	5.707		0.327	3.616	-0.3147	.754
Language								
OA-ND	45			27				
Verbal fluency (ACE III)		0.365	2.311		0.280	1.458	0.620	.535
Boston Naming Test		0.279	1.804		0.000	1.803	0.418	.676

Note:

[a]The difficulty increases from level 1 (the easiest) to level 3 (the most difficult one)

[b]OA-ND – Non-demented older adults

[c]Outcome measures for which significant differences between pretest and posttest were noted

Figures

Figure 1

Sample screens from the GRADYS game: (a) location "at home"; (b) location "out of home".

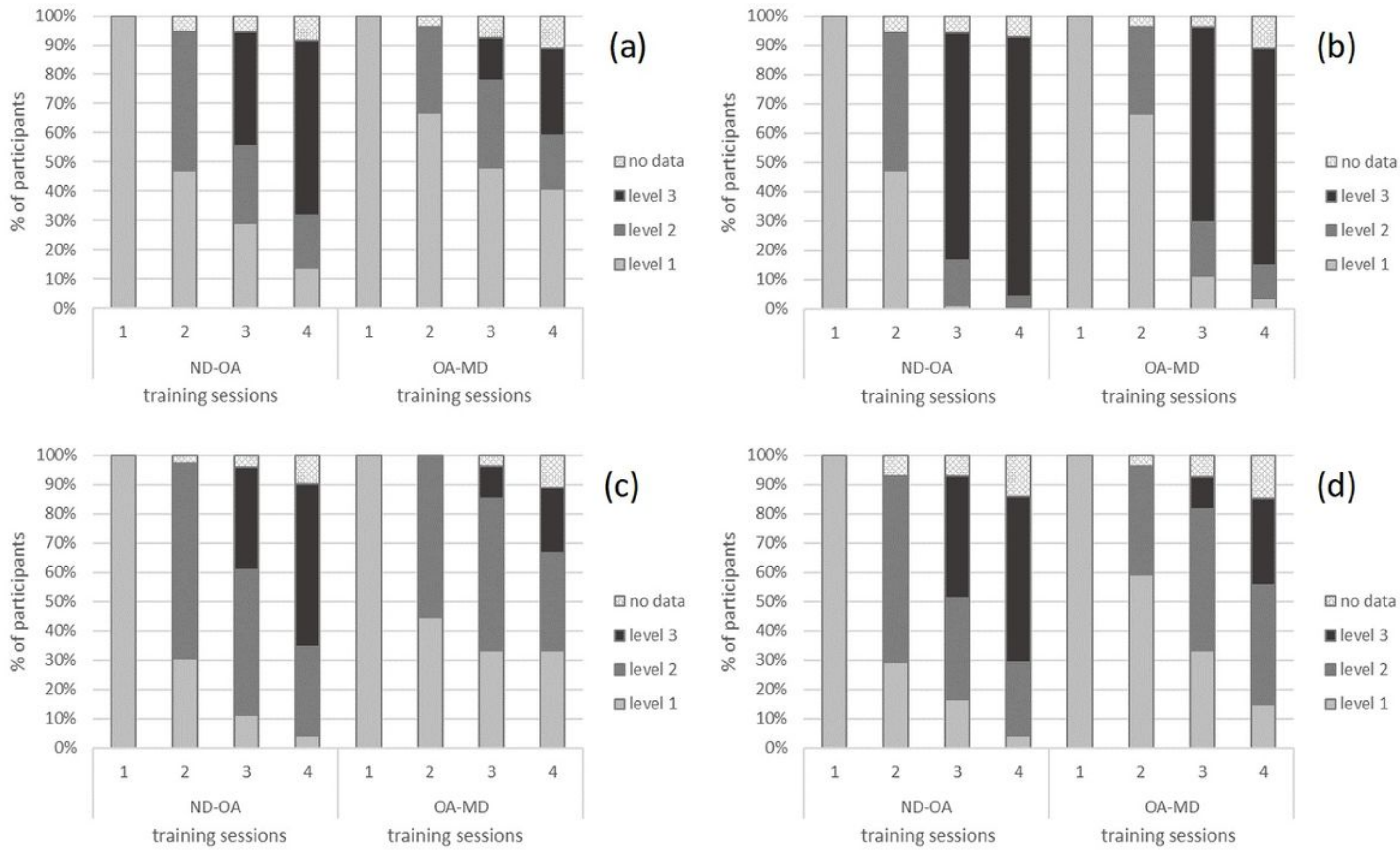

Figure 2

Percentage of participants from the groups of non-demented older adults and older adults with mild dementia who achieved particular levels of difficulty in subsequent training sessions in the following game modules: (a) memory; (b) attention; (c) visuospatial processing; (d) language Note: OA-ND – Non-demented older adults OA-MD – Older adults with mild dementia level 1, level 2, level 3 – levels of difficulty (from the easiest one to the most difficult) no data - the lack of data is the result of the problems with transferring data from the software to the database, which occurred a few times training sessions: 1, 2, 3, 4 - subsequent training sessions in the intervention procedure