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Virtual reality in cognitive interventions for older adults and its application in the GRADYS training software

Wirtualna rzeczywistość w interwencjach poznawczych skierowanych do osób starszych oraz jej zastosowanie w oprogramowaniu treningowym GRADYS

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Abstract

In the era of aging societies, research into methods of cognitive rehabilitation in clinical populations and cognitive enhancement in healthy older adults has soared recently. The growing interest in this area has stimulated the development of technologically advanced computerized training, and solutions based on virtual reality (VR) are emerging. In the article, we discuss the opportunities for the use of VR in cognitive stimulation in older adults. Moreover, we present GRADYS training software, which is a newly developed computerized VR-based cognitive training, which consists of separate game scripts to stimulate four different cognitive domains: attention, memory, language, and visuospatial processing. The GRADYS software has been designed to work in the VR mode with the Oculus Rift. Considering current trends in cognitive rehabilitation and the needs of aging societies, the VR-based software might become a valuable specialized aid utilized in cognitive interventions in older adults. (Gerontol Pol 2017; 25: 248-253)

Key words: *virtual reality, cognitive aging, dementia, mild cognitive impairment, cognitive training.*

Streszczenie

W dobie starzenia się społeczeństw rośnie liczba badań nad metodami rehabilitacji poznawczej w populacjach klinicznych i usprawnienia poznawczego wśród zdrowych osób starszych. Wzrost zainteresowania tym zagadnieniem stymuluje obserwowany rozwój zaawansowanych technologicznie skomputeryzowanych aplikacji treningowych oraz rozwiązań bazujących na wirtualnej rzeczywistości (VR). W artykule omawiamy możliwości wykorzystania VR do stymulacji poznawczej osób starszych. Ponadto prezentujemy oprogramowanie treningowe GRADYS, które jest nowym skomputeryzowanym i bazującym na VR treningiem poznawczym złożonym z niezależnych gier stymulujących cztery różne funkcje poznawcze: uwagę, pamięć, funkcje językowe i funkcje wzrokowo-przestrzenne. Środowisko VR w oprogramowaniu GRADYS jest prezentowane użytkownikowi za pomocą urządzenia Oculus Rift. Biorąc pod uwagę współczesne trendy w rehabilitacji poznawczej oraz potrzeby starzejących się społeczeństw, oprogramowanie bazujące na VR może stać się cenną specjalistyczną pomocą wykorzystywaną w interwencjach poznawczych u osób starszych. (Gerontol Pol 2017; 25: 248-253)

Słowa kluczowe: *wirtualna rzeczywistość, poznawcze starzenie się, otępienie, łagodne zaburzenia poznawcze, trening funkcji poznawczych*

Introduction

In the last decade, neuroscientists have begun to embrace cognitive therapy based on virtual reality (VR) [1-3] in order to aid people with different types of disorders. The use of VR in cognitive interventions is a new area of growing interest in cognitive psychology and neuropsychology as it enables neuroscientists to create

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situations which resemble real life, but with experimental control. Thanks to VR equipment, participants can carry out cognitive and sensorimotor activities in an artificial world and have a feeling of immersion [4].

So far VR has been applied mostly for neuropsychological diagnosis and rehabilitation in several patient groups. There have been studies on intellectual disabilities [5]; autism spectrum disorder [6]; brain damage [3]; focal epilepsy [2]; anxiety disorders [7]; pain remediation [8]; and stroke recovery [9].

Older adults constitute an important target group of VR technology due to cognitive aging [10]. As the human brain and cognition change across the life span, such interventions might be especially applicable in aging populations.

Aging, cognitive decline and cognitive interventions for older adults

There is no general agreement on the definition of "the old age". However, it is often assumed that it starts with 60 or 65 years of age [11]. According to the United Nations, the cut-off point for older population is 60 years of age [12].

Cognitive disorders, such as dementia and mild cognitive impairment (MCI), are major causes of disability and dependency in older age. With life expectancy increasing, prevalence and incidence projections indicate that the number of people with dementia will continue to increase. According to the World Health Organization [13], the number of people with dementia worldwide in 2010 was estimated at 35.6 million and is projected to nearly double every 20 years. A review of prevalence studies that recruited participants at 60 years and older revealed that the prevalence estimates of MCI ranged from 16% to 20% for the majority of the reviewed studies [14]. Moreover, a certain degree of cognitive decline is also observed in normal aging, especially within some aspects of memory, and attention, processing speed, executive function and reasoning [10,15]. In conclusion, the spectrum of cognitive decline ranges from normal cognitive aging to dementia.

There have been various types of cognitive interventions used in older adults so far. Cognitive training, cognitive rehabilitation, and cognitive stimulation are the most popular approaches [16]. According to a systematic review by Martin et al. [17], cognition-based interventions for healthy people and people with MCI have little effectiveness. Although such interventions lead to performance gains, the effects could not be attributed to cognitive training, because the observed improvements did not exceed the improvement in active control conditions. On the other hand, Tardif and Simard [18], in their review on the efficacy of 14 cognitive intervention programs administered to healthy older adults, observed improvement on at least one measure in each study they examined. Moreover, a meta-analysis of 49 researches on the effectiveness of executive control and working memory training indicated not only a significant improvement of performance in training tasks but also near- and far-transfer effects [19].

Possibilities of the use of virtual reality in cognitive interventions for older adults

So far computer technology has advanced, VR has mostly been used to assess cognition in older adults. There have been studies showing the usability and validity of VR for the purposes of cognitive assessment in older adults [20-22]. In memory research, VR has been used to investigate spatial memory [23] and episodic memory [21]. Moreover, the study by Lesk et al. [24] showed its usefulness for the detection of cognitive decline. With the use of a VR-based simulation designed to assess visuospatial memory, the authors were able to correctly differentiate between healthy older participants and those with MCI.

In addition to the use of VR in cognitive assessment, in older adults this technology may be used also for training and rehabilitation purposes. Various VR applications today address cognitive training in MCI. They mostly focus on navigation skills, cognitive functionality and other instrumental activities of daily living [25]. VR has also been used for training of everyday activities in patients with Alzheimer's disease. Foloppe et al. [26] have developed a dual-modal VR platform for training everyday cooking activities in AD patients. They concluded that their findings (only one participant was involved) provided preliminary support for the value of this method for improving cooking activities in Alzheimer's disease. There are still few studies on the effectiveness of cognitive training with the use of VR and researchers are encouraged to pursue this direction [1].

In view of the limited number of studies on the use of VR in cognitive training, certain premises on its effectiveness derive from research on other forms of computerized cognitive training. A meta-analysis on the effectiveness of cognitive training with the use of new technology indicates that such training is at least equally effective or even more effective when compared to a traditional training conducted in a laboratory setting with non-computerized methods [27]. However, most of the studies included in this meta-analysis did not include VR-based training methods (the criterion was the computerized nature of the intervention) and were conducted only in healthy individuals. In turn, a systematic review of the effects of cognitive training and rehabilitation in patients with Alzheimer's disease and vascular dementia revealed a lack of sufficient evidence for the effectiveness of these interventions [28]. However, in this review different forms of intervention were taken into account, including non-computerized ones. Moreover, none of the analyzed intervention used VR.

Going further, in clinical neuropsychology, the generalization of performance from laboratory and clinical situations to relatively everyday life context [29] is an important issue. By providing individuals with immersive naturalistic stimuli that mimic real life, ecological validity of the experimental environment may be increased. There are research findings suggesting that cognitive training related to every-day activity increases the possibility of greater progress [30]. Whereas, when it comes to the use of VR, it is assumed that the psychological experience of "presence" induced by virtual environment boosts learning process and makes it easier to transfer practice effects onto a more general functioning [31].

Finally, it is important to keep the user motivated to actively engage in training. The category of intervention referred to as "a serious game" serves this purpose. The expression "a serious game" was used long before the diffusion of computer technology, in 1970s by Clark Abt [32]. According to a contemporary definition by B. P. Bergeron "a serious game" means an "interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play and engaging, incorporates some scoring mechanism, and supplies the user with skills, knowledge or attitudes useful in reality" [33]. So far, serious games have been used in a wide range of fields, e.g. healthcare, education and training, communication, politics and defence [34]. Thanks to providing a balanced combination between challenge and learning, a serious game allows to maintain the interest and motivation of the user, creating a perfect framework for the cognitive training for older adults [35].

Although VR provides new capabilities in the area of cognitive enhancement in older adults, so far very few programs have been developed to influence the cognitive functioning of older people using this technology.

GRADYS software: a cognitive training with virtual reality elements for cognitive enhancement in older adults

The GRADYS software allows to conduct an intensive cognitive training for people over 60 years of age without cognitive impairment and those with MCI to mild dementia. GRADYS scenarios were planned to simulate situations with the necessary degree of experimental control over key variables. A VR-based cognitive training by ensuring a rich interactive multimodal environment can provide its users with experience that is closer to every-day living than standard computer interfaces or a paper-and-pencil training. It may give participants a feeling of immersion. Moreover, the GRADYS training is a serious game. Tasks are not separated from each other but combined into a mimicry of everyday life. Other "gamification" elements include: transitioning to the next level of difficulty, tracking results in a given session, improving them in subsequent training sessions, and comparing results with other users of the software. The development of the scenarios of cognitive tasks for GRADYS was attended by a team of specialists working with older adults: psychologists, physicians, physiotherapists and volunteers. All scenarios mimic everyday life situations, often encountered in the Polish society, preserving their neutral worldview.

Training settings and procedure

- Cognitive domains: There are separate game scripts for four different cognitive domains: attention, memory, language, and visuospatial processing. Each cognitive domain has its own gameplay, composed of several tasks involving the same cognitive function and forming a coherent storyline inspired by everyday life. The player can engage in a training of various cognitive domains in any order and any number of times. The software includes a tutorial. It is used to learn how to play the game and how to use the Oculus and the control pad.
- Location versions of the game: For each cognitive domain two versions of game scripts have been developed, differing with regard to the environment they depict: in one, the game takes place at home and in the other, out of home. The apartment utilized in the 4 home scripts is the same environment. However, depending on the task, the script takes place in different locations of the apartment (e.g. at a kitchen table, at the front door, in the bathroom). Environments out of home differ from each other and include such places as: a street, a market square, a railway station, and others.
- Difficulty levels: For each module, three difficulty levels have been designed. The structure and logic of the tasks, however, are analogical across all difficulty levels. The difficulty level is increased by raising the cognitive demands on the particular domain the script

focuses on, e.g. a higher number of elements to memorize in the memory module, a higher number of distractors and their similarity to the target in the attention module, an increased visuospatial complexity of objects in the visuospatial module, and an increased syntax complexity and vocabulary difficulty in the language module. It is recommended to begin always with the easiest level. The player moves to a higher level having reached 75% accuracy. In the case of accuracy falling below 50%, the player returns to a lower level of the game. Regardless of these rules, the player can choose any level of difficulty manually returning to the launch menu.

- Control settings: The game can be controlled with the Oculus Rift and a control pad or with a computer keyboard and a mouse. However, it is strongly recommended to use the Oculus variant because only this device allows the player to immerse in a three-dimensional VR. The VR headset supports head movements with 6 degrees of freedom (unconstrained rotation and head positioning limited by wires). The control pad provides older adults with an ergonomic interface, preventing improper selection, and a limited number of action triggers, which together considerably simplify interface mastering. In addition, it is possible to select handedness.
- Communication: During gameplay, all communications with the player are simultaneously displayed on the screen and read for the player by a narrator. At the end of each task, and sometimes after performing a single action in the task, depending on the game, the player is given both audio and visual feedback. The player is familiarised with all feedback sounds and symbols in the tutorial. After finishing a single gameplay (e.g. attention module at home), accuracy and response time feedback is displayed on the screen, which contains the following information: (a) mean accuracy percentage (recommended as the criterion for difficulty selection in the next session); (b) accuracy percentage for each task; (c) error number for each task; (d) response time for each task.

Technological aspects

Respecting the lack of immersive environment experience among presumed users, the Oculus Rift DK2 was selected for visualization with an initial preferred view direction and an unconstrained freedom of environment detail acquisition - unconstrained head positioning, whereas the XBox 6DOF game pad as a supporting controller. The proposed digital camera navigation was designed as a semiautomatic mode: after completing each task the user is transferred automatically to a subsequent task location with an initial preferred view direction. The smoothness and speed of the movement was empirically adjusted to the size of the environment and tested among users (compromise between the navigation dynamics and the VR sickness effect). The whole system was implemented with the Unity Pro 5.0 game engine with built-in drivers for external controllers.

Discussion

Cognitive ability has a particular significance for the quality of one's functioning in the society and subjective quality of life. A high level of cognitive functioning is one of the factors that underlie successful aging [36]. In this context, maintenance of a relatively high level of cognitive functioning, both in healthy older adults, as well as in those with dementia, is a priority. There is a growing need for ecologically valid methods that may enhance cognitive and everyday functioning in late adulthood. One of possible answers to this need may be the use of VR in cognitive interventions for older adults.

The GRADYS software we propose fills two gaps in research on the potential for the VR use in cognitive training in persons over 60 years of age. The first is the focus of existing research and training tools only on the older adults, who reveal cognitive deficits. There are no VR tools developed for prevention in older population without deficits. GRADYS is intended to be used as a preventive or rehabilitation tool in both groups. Secondly a possible consequence of designing tools only for people with cognitive disorders results in their orientation to teach specific everyday life activities. In the GRADYS software, VR is used for more general cognitive stimulation, oriented more on cognitive processes THAN on algorithms. What is important, our VR-based training is a proposal of cognitive intervention that uses new technologies and solutions to enable cognitive stimulation in more environmentally-friendly conditions (through VR environment and everyday-life-like tasks) and maintain engagement and motivation (thanks to the "serious game" convention).

Conclusions

In conclusion, there is a need of developing effective yet appealing forms of cognitive intervention for older adults, not only in terms of rehabilitation but also prevention of cognitive decline. Although there is a rapid growth in the use of VR solutions among researchers, and some supporting results have been acquired, we still remain far from a widespread implementation. Since VR systems are constantly dynamicly changing (they are becoming smaller, more mobile, cheaper, and more adaptable), our program may offer even more optimized specialistic aid for cognitive training.

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Conflict of interest

None

References

1. Garcia-Betances R, Jimenez-Mixco V, Arredondo M. Using virtual reality for cognitive training of the elderly. Am J Alzheimers Dis Other Dement. 2014;30(1):49-54.
2. Grewe P, Lahr D, Koshik A, et al. Real-life memory and spatial navigation in patients with focal epilepsy: Ecological validity of a virtual reality supermarket task. Epilepsy Behav. 2014;31:57-66.
3. Rose FD, Brooks BM, Rizzo AA. Virtual reality in brain damage rehabilitation: review. Cyberpsychol Behav. 2005;8(3):241-62.
4. Fuchs P, Moreau G, Berthoz A, et al. Le traité de la réalité virtuelle volume 1 - L'Homme et l'environnement virtuel. {Treaty of virtual reality-Vol. 1. The man and the virtual environment}. Paris, Press d'Ecole des Mines de Paris; 2006.
5. Standen PJ, Brown DJ. Virtual reality in the rehabilitation of people with intellectual disabilities: review. Cyberpsychol Behav. 2005;8(3):272-82.
6. Kandalaft MR, Didehbani N, Krawczyk DC, et al. Virtual reality social cognition training for young adults with high-functioning autism. J Autism Dev Disord. 2013;43:34-44.
7. Gorini A, Riva G. Virtual reality in anxiety disorders: the past and the future. Expert Rev Neurother. 2008;8(2):215-33.Mahrer NE, Gold JI. The use of virtual reality for pain control: a review. Curr Pain Headache Rep. 2009;13(2):100-9.
8. Cameirăo MS, Badia SI, Oller ED, et al. Neurorehabilitation using the virtual reality based Rehabilitation Gaming System: methodology, design, psychometrics, usability and validation. J Neuroeng Rehabil. 2010;748. doi:10.1186/1743-0003-7-48.
9. Harada CN, Love MN, Triebel K. Normal Cognitive Aging. Clin Geriatr Med. 2013;29(4):737-52.
10. Sagner A, Kowal P, Dowd JE. Defining "Old Age". Markers of old age in sub-Saharan Africa and the implications for cross-cultural research. Technical Report, WHO; 2002.
11. United Nations, General Assembly resolution 35/129, Problems of the Elderly and the Aged: Resolution (A/RES/35/129).
12. World Health Organization. Dementia: a public health priority. 2012.
13. http://apps.who.int/iris/bitstream/10665/75263/1/9789241564458_eng.pdf?ua=1 Accessed: 18 September 2017.
14. Roberts R, Knopman DS. Classification and Epidemiology of MCI. Clin Geriatr Med. 2013;29(4):1-19.
15. Murman D.L. The Impact of Age on Cognition. Seminars in Hearing 2015;36(3):111-21.
16. Stine-Morrow EAL, Basak C. Cognitive Interventions. In: Schaie KW, Willis SL (eds) Handbook of the Psychology of Aging. 7th Edition. San Diego, CA: Academic Press; 2011. p. 153-171.
17. Martin M, Clare L, Altgassen AM, et al. Cognition-based interventions for healthy older people and people with mild cognitive impairment. Cochrane Database Syst Rev. 2011;(1):CD006220. doi: 10.1002/14651858.CD006220.pub2.
18. Tardif S, Simard M. Cognitive stimulation programs in healthy elderly: a review. Int J Alzheimers Dis. 2011;378934. doi: 10.4061/2011/378934.

19. Karbach J, Verhaeghen P. Making working memory work: a meta-analysis of executive-control and working memory training in older adults. Psychol Sci. 2014;25(11):2027-37.
20. Cushman LA, Stein K, Duffy CJ. Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. Neurology. 2008;71(12):888-95.
21. Plancher G, Gyselinck V, Nicolas S, et al. Age effect on components of episodic memory and feature binding: A virtual reality study. Neuropsychology. 2010;24(3):379-90.
22. Werner P, Rabinowitz S, Klinger E, et al. Use of the virtual action planning supermarket for the diagnosis of mild cognitive impairment: a preliminary study. Dement Geriatr Cogn Disord. 2009;27:301-9.
23. Parsons TD, Rizzo AA. Initial validation of a virtual environment for assessment of memory functioning: virtual reality cognitive performance assessment test. Cyberpsychol Behav. 2008;11(1):17-25.
24. Lesk VE, Shamsuddin SNW, Walters ER, et al. Using a virtual environment to assess cognition in the elderly. Virtual Reality. 2014;18(4):271-9.
25. Jekel K, Damian M, Wattmo C, et al. Mild cognitive impairment and deficits in instrumental activities of daily living: a systematic review. Alzheimers Res Ther. 2015;7(1):17. doi: 10.1186/s13195-015-0099-0.
26. Foloppe D.A, Richard P, Yamaguchi T, et al. The potential of virtual reality-based training to enhance the functional autonomy of Alzheimer's disease patients in cooking activities: A single case study. Neuropsychol Rehabil. 2015;20:1-25.
27. Kueider AM, Parisi JM, Gros AL, et al. Computerized cognitive training with older adults: a systematic review. PloS One. 2012;7(7):e40588. doi: 10.1371/journal.pone.0040588.
28. Bahar-Fuchs A, Clare L, Woods B. Cognitive training and cognitive rehabilitation for persons with mild to moderate dementia of the Alzheimer's or vascular type: a review. Alzheimers Res Ther. 2013;5(4): 35. doi: 10.1186/alzrt189.
29. Wilson BA. Neuropsychological rehabilitation. Annu Rev Clin Psychol. 2008;4:141-62.
30. Willis S, Tennstedt S, Marsiske M. Long-term effects of cognitive training on everyday functional outcomes in older adults. JAMA. 2006;296(23):2805-14.
31. Coyle H, Traynor V, Solowij N. Computerized and virtual reality cognitive training for individuals at high risk of cognitive decline: systematic review of the literature. Am J Geriatr Psychiatry. 2015;23(4):335-59.
32. Ricciardi F, De Paolis LT. A Comprehensive Review of Serious Games in Health Professions. Int J Computer Games Tech. 2014; Article ID 787968, doi:10.1155/2014/787968.
33. Graafland M, Schraagen JM, Schijven MP. Systematic review of serious games for medical education and surgical skills training. Br J Surg. 2012;99(10):1322-30.
34. Djaouti D, Alvarez J, Jessel, J-P. Classifying Serious Games: The G/P/S Model. In: P. Felicia (Ed.). Handbook of Research on Improving Learning and motivation through Educational Games: Multidisciplinary Approaches. Hershey: IGI Global; 2011. p. 118-136.
35. Laskowska I, Zając-Lamparska L, Wiłkość M, et al. A serious game - a new training addressing particularly prospective memory in the elderly. Bio-Algorithms and Med-Systems 2013;9(3):155-65.
36. Zając-Lamparska L. Psychologiczne koncepcje pomyślnego starzenia się człowieka (Psychological concepts of successful aging). Rocznik Andragogiczny (Andragogy Yearbook) 2012;18:89-105.