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VIRTUAL REALITY-BASED COGNITIVE STIMULATION USING GRYDSEN SOFTWARE AS A MEANS TO PREVENT AGE-RELATED COGNITIVE-MOBILITY DISORDERS – A PILOT OBSERVATIONAL STUDY

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Abstract: *The human aging process is associated with systematic deterioration of cognitive and motor performance. Age-related deficits in motor skills and symptoms of cognitive decline, such as memory, attention and executive functioning problems, are major contributors to a loss of functional independence and reduced quality of life of the elderly. The virtual reality system presented can be used as an aid for effective training of those skills. The use of virtual reality training for therapeutic purposes is promising – not only does it provide encouraging medical and psychological effects but it may also be considered as an interesting leisure activity for seniors. The paper presents a pilot study which aims to qualitatively assess the usefulness of a VR technology-based solution for training cognitive and motor functions. The pre-test phase of the study was conducted on 9 subjects aged 62-81 (M = 71.66; SD = 7.00), who were asked to evaluate the performed tasks in terms of novelty and attractiveness. All subjects completed the pilot study. The SUS result was 55.56 (SD = 9.90), which is a marginal result. However, the UEQ result showed that all aspects of the game were reported as satisfactory. The pilot studies show that VR is well tolerated by the elderly. As demonstrated by the results, the system has moderate utility, but may be a promising solution for training cognitive-motor skills.*

Keywords: *virtual reality, cognitive training, motor training, elderly, cognitive decline, rehabilitation.*

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INTRODUCTION

The problem of cognitive decline in the elderly

The world's population is aging at an unprecedented rate. A systematic increase of human life expectancy carries with it specific social, economic and health consequences. It is forecasted that the number of elderly people will more than double in the near future, reaching over 1.5 billion in 2050 (United Nations Department of Economic and Social Affairs, Population Division, 2020). With the accelerated aging of the population, the incidence of age-related disorders, including cognitive and motor dysfunctions, will also continue to increase (Peng et al., 2019).

As people grow older, there is a gradual decline in cognitive functions. This process is referred to as cognitive aging (Harada et al., 2013). However, not all cognitive functions are equally affected by age-related changes. Some aspects of memory and attention are particularly sensitive to the effects of aging (Glisky, 2007). In terms of memory, the greatest involutional changes are observed for episodic memory, working memory and the encoding of new information in long-term memory (Grady, 2008; Murman, 2015). In terms of attention, the functions that deteriorate most with age are selectivity, divisibility and shifting. In addition, higher-order cognitive functions, such as linguistic processing and decision-making, may also be impaired. However, the key factor contributing to the deterioration of cognitive functioning in late adulthood is the impairment of executive functions that progresses with age (Glisky, 2007). Age-related deficits in cognitive skills may gradually affect an individual's ability to function effectively in everyday life, thus contributing to social withdrawal.

As the number of individuals with age-related cognitive disorders and motor problems is expected to increase significantly during the next 30 years, it is necessary to actively seek innovative training methods to slow down the side effects of aging and, consequently, support the maintenance of functional independence of seniors.

The problem of motor disorders in the elderly

The aging process gradually impacts one's ability to perform daily functional activities. These limitations are associated with changes in the neuromuscular system, which include reduced muscle strength, power, endurance and increased fatigability. As argued by Hunter et al., these limitations are related to changes in motor units (Hunter, Pereira, Keenan, 2016). Additionally, another age-related problem is the reduction in the range of joint mobility, partly due to changes in the connective tissues (Freemont, Hoyland, 2007; Yamada, et al., 2002). This makes it difficult to perform motor activities. The motor performance of the elderly is also impaired due to disturbed anticipatory motor planning. Stockel et al. suggest that anticipatory motor planning abilities are strongly influenced by cognitive control processes, which seem to be the key mechanisms to compensate for age-related decline (Stöckel, Wunsch, Hughes, 2017).

The use of VR to improve cognitive and motor functioning in the elderly

The use of virtual reality (VR) offers many new possibilities in the field of intervention and broadly understood therapy for older adults. Compared to traditional interventions based on the paper-and-pencil method, VR training offers the possibility of flexible adaptation of exercises to the needs and cognitive abilities of the patient (Coyle et al., 2015). In addition, training of this type is characterized by ecological accuracy. This means that the tasks performed refer to the skills used in everyday life. Another advantage of VR training is that it allows the users to explore the environment on their own. This has a positive effect on the development of self-efficacy and a sense of independence during therapy. An additional advantage is the possibility to incorporate the gamification factor, which results in an increased level of motivation and commitment to training (de Bruin et al., 2010).

The conclusions from the systematic literature review indicate that the use of computerized or VR-based cognitive training in the elderly gives comparable or better effects in terms of improving cognitive functions compared to traditional methods (Zając-Lamparska et al., 2019). Research data show improvements in executive function, attention, visual memory, and long-term memory in people who have undergone VR training (Gamito et al., 2020; Optale et al., 2010). There are also more reports indicating the high effectiveness of VR in the training of motor functions (Lee, Lee, Song, 2018; Calabro et al., 2017; Molhemi et al., 2020). Taking into account the cited data, it can be concluded that the use of VR is an effective method of cognitive training.

Difficulties in functioning in VR in the elderly

The research conducted so far shows that VR is well tolerated by the elderly (Lin, Lee, Lally, Coughlin, 2018; Syed-Abdul et al., 2019; Benoit et al., 2015; Wojciechowski et al., 2021). The study of Benoit et al. highlighted that those participants did not experience sickness during the experiment across the VR conditions (Lin, Lee, Lally, Coughlin, 2018). Syed-Abdul S. et al. conclude that participants of their study perceived VR as a beneficial, user-friendly and enjoyable experience, implying positive attitudes toward adopting this new technology.

However, it is worth noting that the positive attitude of older people towards new technologies and virtual environments is verified by their real functionality. Improperly designed application or environment can discourage users despite their initially positive attitude.

Older people perceive color contrast differences less efficiently, especially in the area of blue-green tones. For this reason, it is necessary to rely mainly on the luminance of colors (C. Owsley et al., 1983). Additionally, colors should be used according to expectations and accepted conventions, e.g. red means "stop" while green means "go".

Since the visual field of older people is narrower, the area of interest should be focused as close to the center of the visual field as possible (Cerella, 1985). For example, interface elements should be concentrated in the center of the display. Graphics should be kept as simple as possible to eliminate distractors, such as animation, patterns on walls, and glowing text (W. Kosnik et al., 1988). Typically, older people have poorer vision and worse ability to see details, so interface elements, including text, should be larger and more legible. Gaze control or the use of gaze to interact with the environment is also limited. Inexperienced users explore the scene space quite nervously and impulsively with their eyes. As a consequence, using gaze as an input interaction channel can be ineffective (Wojciechowski et al., 2014).

An important component of a virtual reality system is the auditory stimuli. However, it should be remembered that the ability to recognize sounds of different frequencies decreases with age. Sounds above 2500 Hz are usually inaudible (Berkowitz J.P. et al., 1990) so instructions and other auditory events should refer to lower frequencies. The frequency range between 500 and 1000 Hz is considered optimal for older users.

Memory performance is strictly related to the simplicity of tasks conducted by elderly people. No more than 5∓2 related items should be presented on the display panel. The elderly use long-term memory much more effectively than short-term memory. In consequence, their ability to recall something from experience is much better than learning something new. Thus, user interface design should focus on using functions or graphics that may rely on the functions on those instruments learnt in the past. Commands should be straightforward and not create confusion to the user to prevent them from possible misunderstanding and losing recognition of the functions in the short term.

Physical decline is an additional problem affecting older users' interaction with computer systems. Seniors may have problems with the response speed rather than complexity of use. Fisk et al. (2020) reported difficulties in the use of double click, but when interval time was increased, the difficulties appeared to be lower. Older users may have difficulties finding small targets in an interface and performing movements with high accuracy (Andrzejczak et al., 2021). Hand-controlled interfaces can be excessively challenging for older users because of the lack of precision of movement, individual differences in movement characteristics, and the lack of adequate visual feedback (Półrola et al., 2012).

All the above findings suggest that seniors may find it difficult to interact in a virtual environment that was not designed specifically for them. Having in mind all the above issues and considering the promising findings of cognitive rehabilitation (Zając-Lamparska et al., 2019) a new gamified virtual reality environment was designed and implemented, which may serve both cognitive stimulation and physical rehabilitation purposes.

MATERIALS AND METHODS

Purpose

Due to the specificity of immersive training dedicated to the elderly, and the desire to create a game that would suit seniors both technically and qualitatively, we asked the senior players detailed research questions before implementing the full version of the interface.

As part of a varied pilot study of the GRYDSEN interface, we want to check whether:

- game scenarios are correctly formulated,
- the interface is adapted to the needs of the elderly,
- the instructions are exhaustive enough for the audience.

In addition, we want to qualitatively check whether the respondents understand the game, their interest, opinion and the way they react to selected scenarios.

Participants

The study was conducted in 2021. Participation in the study was voluntary, people who had signed informed consent to participate in the project were enrolled immediately. Only adults over 60 years of age participated in the study, with no upper age limit. All participants were informed that they could withdraw from the study at any stage. Only full questionnaires were included in the analysis. The pilot study was conducted on a purposefully selected sample – 9 people over 60 years of age. People with contraindications to VR games were excluded from the study. In addition, the inclusion criterion was the lack of cognitive impairment (MMSE> 27 points) (Nitrini et al., 1994).

Ethical Considerations

The study was approved by the Bioethics Committee of the Nicolaus Copernicus University Collegium Medicum in Bydgoszcz, Poland (KB 426/2021). The research was conducted in accordance with the Helsinki Declaration. All participants provided informed consent for the research.

Outcome measures

Before proceeding with the pilot study, all potential participants completed an introductory interview assessing the inclusion criteria. The interview consisted of two parts. The first one referred to the sociodemographic data, such as age, gender, place of residence, marital status, educational level, number of years of study, acquired profession, and professional status. The second part referred to the basic information related to the health status, such as previous head injury, concussion, or meningitis, experiencing epilepsy, stroke, dizziness, motion sickness, or any somatic or mental diseases. The questions concerning hearing or musculoskeletal system impairment and physical activity were also included.

The three evaluation sheets of game tasks were self-constructed. They assess the user experience of cognitive, motor, and motor-cognitive tasks and provide a subjective view of their accessibility.

The motor task evaluation sheet consists of 6 items rating from 0 to 10. They refer to the evaluation of graphic design, safety, clarity of the statements, task difficulty level, time dedicated to solving the task, fatigue, level of immersion and ease of attendance. The other comments or suggestions are also included. The cognitive task evaluation sheet consists of 7 items rating from 0 to 10. They evaluate the number of tasks included, time dedicated to solving the task, clarity of statements, task difficulty level, readability of the displayed text and graphic design, and usefulness of the hints. The possible comments are also included. The cognitive-motor task evaluation sheet consists of 7 items rating from 0 to 10. The construction of this task allowed the usage of the previous, cognitive task evaluation sheet. All items, except the item concerning the hints, are the same.

The User Experience Questionnaire (UEQ) (Laugwitz, Schrepp, Held, 2008) is a fast and reliable questionnaire to measure the user experience of a product. It consists of 6 scales with 26 items with seven response options. The scales refer to attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty.

The System Usability Scale (SUS) (Brooke, 1986) is a scale concerning subjective assessments of the usability of a product. It consists of 10 items with five response options: from strongly agree to strongly disagree. The scale is widely used and provides a high-level subjective view of usability. The score ranges from 0 to 100.

GRYDSEN

As part of the GRYDSEN project, separate modules for training the cognitive, motor and cognitive-motor functions were developed. As part of the pilot study, three scenarios were tested, one for each of the modules replaced (Fig. 1).

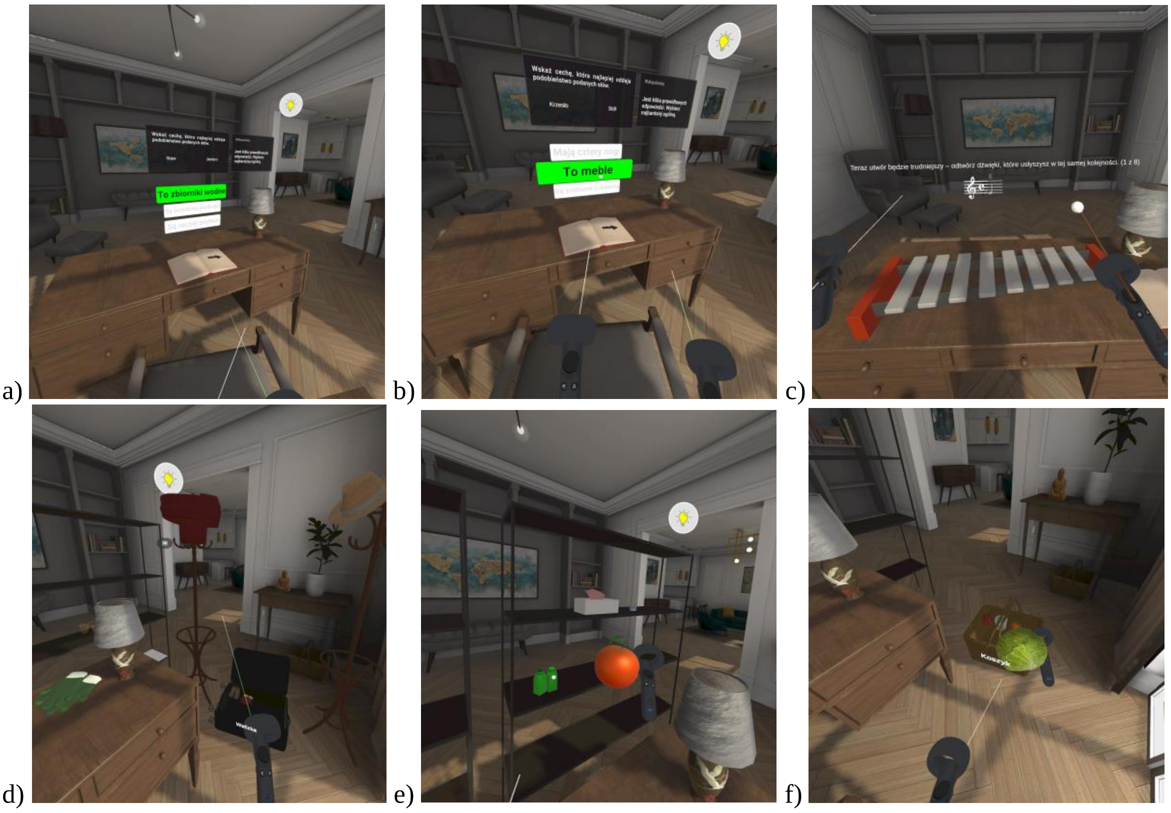

Figure 1. The GRYDSEN cognitive, motor and cognitive-motor modules. a), b) - ANALOGIES (cognitive), c) - XYLOPHONE (motor) and d), e), f) - EVERYDAY ACTIVITIES (cognitive-motor) modules previews from user (VR headset) perspective.

Overall, the scenes, and their equipment, were designed to meet the aforementioned guidelines for designing virtual environments for the elderly. Appropriate color scheme (background objects in gray colors, interactive objects of appropriate size and color/brightness contrast), appropriate readability of text commands, the appropriate number of interactive objects, lack of details and distractors, clear way of object selection supplemented with both visual and audio feedback are only the main of many procedures for improving the usability and functionality of the tested VR environment.

Cognitive functions module: The ANALOGIES task has been created for the training of cognitive functions. The implemented project assumes that the scenarios from the "Cognitive Training" module will primarily involve attention, executive function and memory (operational, long-term, retrospective, prospective). The pilot study focused on inference by analogy. Tasks of this type refer to the ability of an individual to detect the relationship between different objects and the ability to use the same inference / problem-solving schemes under different conditions. The skill training inferred by analogy is especially recommended to stimulate the attention function. Reasoning by analogy covers a wide class of tasks. The described scenario included tasks that required the participant, among others, the ability to point out opposites and similarities, identify words that were related to non-semantic features (e.g. similar spelling, rhyme) or related to objects that belonged to the superior class or had common property. The use of VR required a modification of the classic form of this task, in which the tested person formulates an answer themselves. The scenario was created in such a way that the examined person chooses the answer that best suits them from a catalog of options.

At the very beginning, the user is acquainted with the command and then, using the controller, selects the feature label that best describes the selected objects. The task is repeated several times, for different sets of objects, after which the number of correct answers is recorded. A prolonged lack of the user's response causes the prompt to appear, and the user has an independent option to use the prompt – a light bulb icon in the corner of the screen.

Motor functions module: The task is to strike certain calves of the XYLOPHONE with the sticks. It helps to improve gross and small motor function and involve various muscle groups. In addition, the exercise requires appropriate coordination and precision of movement. The user, standing in front of the xylophone and holding the sticks in his hands (controllers), should play a sequence of sounds. The melody to be played is not only sequentially displayed as notes on a music stave, but also the individual xylophone calves are highlighted in color. The span of xylophone calves and the choice of sounds and length of the sequence itself directly affects the range of upper limb mobility, as well as stimulating short-term memory. In a situation of prolonged thinking, the user has the option to listen to the sequence of sounds again or can get help by clicking on the light bulb icon in the upper right corner of the interface.

Module cognitive-motor functions: The essence of the module is the involvement of cognitive functions (here: memory, attention) and motor functions. The described part of the game concerns both the simulation of everyday life (ecological paradigm) as well as tasks directly used in training the cognitive functions of aging people. The player will be tasked with performing everyday activities. As part of the pilot study, the EVERYDAY ACTIVITIES task and shopping task was tested (Fig. 1). The player's task was to choose items that would be expected, either useful or required, depending on the task. The choice of objects depends on the time of year, leisure activities or an actual shopping list. From the interface, it required reading a command, augmenting conditions or remembering products list and selecting adequate objects. In the case of packing, exemplary staying at the beach in July or visiting a city in autumn, implied a specific set of staff to be selected (Fig 1d). The shopping task required choosing items from the list that needed to be remembered. The puzzle was constructed in such a way as to have several levels of difficulty, i.e. through increasing the number of objects to be selected. The items needed for the trip or to shop were spread all over the room so that the player had to look around the room and "reach" for them. They remained within the player's reach all the time, but their distribution was randomly redistributed within each scenario try. At the very bottom of the screen, you could see a representation of the bag or the shopping cart in which the user had to pack the staff (Fig. 1f). The objects, the suitcase, and the cart to which they were to be put were placed in the room in such a way that the user had to look around activating the upper body part. Additionally, pointing to the objects with the controller pointer as well as placing the objects in the suitcase/basket required moving the upper limbs, which stimulated motor functions. The user could both operate the environment while standing and seating, which prevented loss of balance and increased safety for the participants immersed in VR.

RESULTS

Participants

We recruited 9 people, 5 men and 4 women, to take part in our pilot study. The subjects were aged 62-81 (M = 71.66; SD = 7.00). In the group of respondents, 5 people had higher education and 4 had secondary education background. The average year of education was M = 15.11. All respondents were urban dwellers. The subjects did not suffer from any neurological diseases, serious somatic diseases, or mental disorders. One person declared that he was dizzy. All subjects had a visual impairment, two of them had a hearing impairment.

Assessment of individual tasks

Table 1 summarizes the participants' responses to the Analogies task. The conducted analyzes show that the participants highly rated such aspects of the task as the number of tasks, the time needed to complete them, the readability of the text and the readability of the graphic elements. The respondents assessed the usefulness of the formulated hints as low since the tasks were clear. The degree of difficulty of the tasks was assessed as average.

Table 1. Questions evaluating ANALOGIES tasks.

Questions	M	SD	Min	Max
1. Number of tasks: On a scale of 0 to 10, how would you rate the number of examples in this task?	8.44	1.24	6.00	10.00
2. Execution time: On a scale of 0 to 10, how do you rate the time needed to complete this task?	8.89	0.78	8.00	10.00
3. Clarity and unambiguity of the instructions for performing a task: How do you evaluate the instruction for a task on a scale from 0 to 10? Is it unambiguous?	5.56	1.13	4.00	8.00
4. Task difficulty rating: How would you rate the task difficulty on a scale from 0 to 10?	4.89	1.36	3.00	7.00
5. Evaluation of the usefulness of the hints: How, on a scale from 0 to 10, do you assess the usefulness of the formulated hints?	4.89	0.60	4.00	6.00
6. Readability of the displayed text: How do you assess the readability and/or visibility of the displayed text on a scale from 0 to 10?	8.78	0.97	7.00	10.00
7. Readability of displayed graphic elements: How do you assess the readability of displayed graphic elements on a scale from 0 to 10?	8.89	1.05	7.00	10.00

Note: M – mean; SD – standard deviation; Min – minimum value; Max – maximum value.

Table 2 lists the participants' responses to the Everyday activities task. The conducted analyzes show that the participants highly rated such aspects of the task as: the number of tasks, the time needed to complete them, the clarity of the formulated instructions and usability. This task was rated as difficult by the users. Moreover, the respondents assessed the readability of the text and the graphic elements as low.

Table 2. Questions evaluating of EVERYDAY ACTIVITIES tasks.

Questions	M	SD	Min	Max
1. Number of tasks: On a scale of 0 to 10, how would you rate the number of examples in this task?	9.33	0.71	8.00	10.00
2. Execution time: On a scale of 0 to 10, how do you rate the time needed to complete this task?	9.33	0.71	8.00	10.00
3. Clarity and unambiguity of the instructions for performing a task: How do you evaluate the instruction for a task on a scale from 0 to 10? Is it unambiguous?	9.00	0.87	8.00	10.00
4. Task difficulty rating: How would you rate the task difficulty on a scale from 0 to 10?	8.44	1.33	6.00	10.00
5. Readability of the displayed text: How do you assess the readability and/or visibility of the displayed text on a scale from 0 to 10?	5.89	0.78	5.00	7.00
6. Readability of displayed graphic elements: How do you assess the readability of displayed graphic elements on a scale from 0 to 10?	4.11	1.05	3.00	6.00
7. Usefulness: On a scale from 0 to 10, how would you rate the usefulness of the task performed?	8.56	1.01	7.00	10.00

Note: M – mean; SD – standard deviation; Min – minimum value; Max – maximum value.

Table 3 summarizes the participants' responses to the Xylophone task. The conducted analyzes show that the participants highly rated such aspects of the task as the level of safety during the performance of the task and the level of difficulty of the task. The users evaluated the graphic design and the brightness of the task as average. The level of fatigue during the performance of the task was assessed as low. Moreover, the respondents assessed the motor task as quite difficult to perform.

Table 3. Questions evaluating of XYLOPHONE tasks.

Questions	M	SD	Min	Max
1.Graphic design	6,78	0,97	5,00	8,00
2. Safety (did you feel safe while performing the tasks?)	8,22	0,83	7,00	9,00
3. Clarity of tasks	6,78	1,39	5,00	9,00
4. Task difficulty level	7,89	0,93	6,00	9,00
5. Time dedicated to solving the task	5,67	1,00	5,00	8,00
6. Fatigue / Exercise Level	2,56	1,01	1,00	4,00

Note: M – mean; SD – standard deviation; Min – minimum value; Max – maximum value.

System Usability Scale

The mean of the evaluation of GRYDSEN software in the pilot study using the SUS scale was 55.56 (SD = 9.90). The minimum user rating was 40, and the maximum was 70. According to the table designed by Bangor, the average project value in the ratings of the testers belongs to the categories "ok" and "good", which is in the range of 50-70 (Bangor, Kortum & Miller, 2009). This result means that GRYDSEN software still ha room for improvement.

User Experience Questionnaire

The evaluation of the application carried out with the use of the UEQ tool shows that all assessed aspects of the game stimulating cognitive and motor functions are good (all results above +0.80) (Fig. 2). The respondents highly rated the attractiveness (M = 1.87), stimulation (M = 1.69), and novelty (M = 1.61). Some aspects of the game such as dependability (M = 1.41), efficiency (M = 1.16) and perspicuity (M = 0.92) were assessed slightly lower.

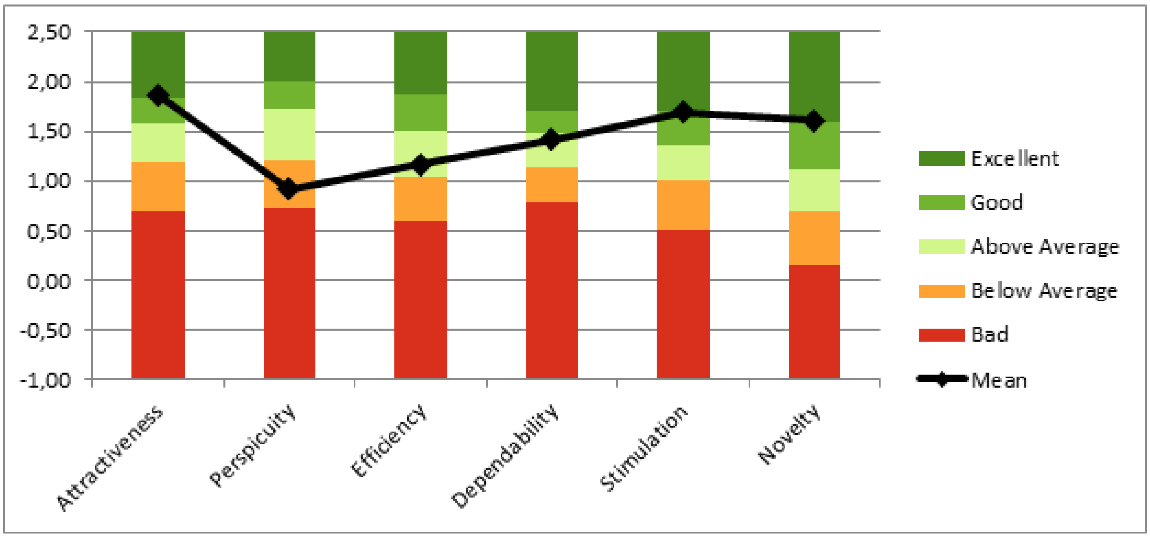

Figure 2. User experience feedback measured on the six UEQ scales for the whole application.

DISCUSSION

The goal of this study was to assess the usability and user's experience of a VR cognitive-motor training system for the elderly. As the rate of aging societies is rapidly increasing, a growing number of age-related disorders will also be observed. This creates the need for solutions that could help strengthen and support the cognitive and motor skills of the elderly (Doniger et al., 2018). The virtual reality system can be used as a platform for effective training of those skills. Virtual reality offers physical and mental benefits for older adults, while also providing entertainment. Moreover, VR is ecologically valid and enables the simulation of daily living activities (Pedroli et al., 2018; Banville et al., 2017). The results of the performed pilot study, concerning the System Usability Scale (55.56, SD = 9.90) and the

User Experience Questionnaire (all results above +0.80) scores, showed that our system can forecast as a fully-flagged cognitive-motor training alternative. The pilot study itself becomes a basis for evaluation as well as improving quality and usability of the system interface. Implementation of the Grydsen improvements will further increase the usability of the system in motor-cognitive exercises in older adults.

The user experience of the system

The SUS score was 55.56 (SD = 9.90), which is a marginal score. However, the UEQ score showed that all aspects of the game were reported as satisfactory. The innovative design of the system does not allow us to compare it with similar systems, especially in terms of user experience. The authors of this study did not find in the literature parallels to the GRYDSEN software, as other researchers focus more on patients with selected diseases than on normally aging adults. In addition, the few available interfaces cover related scopes of the presented tasks, i.e. cognitive, motor and cognitive-motor tasks, in particular those that require the player to multitask. None of the solutions presented in the literature to date has simultaneously addressed so many cognitive-motor modalities and has been implemented with attention to such an in-depth analysis of the needs of older adults. An interesting project dedicated to aging adults is that by Tuena et al. (2020), who conducted a systematic review of usability issues of clinical and research applications of virtual reality in older people. Although this study focused mainly on physiotherapy training, it reported that VR systems are good, well-accepted, adequate, effective, and useful. The authors claim that the skepticism of the elderly concerning digital systems could be successfully reduced by longer exposure to VR. Huygelier et al. (2019) reported that older adults who never had prior experience with VR had a neutral attitude towards this technology. Our pilot study showed similar experiences – despite the anxiety about experiencing the novelty, the elderly responded very positively and declared their willingness to continue participating in the project. Among most of these people, there was a suggestion that people who have never had contact with the VR system should be provided with a tutorial, where they can slowly learn how to navigate this interface. In addition, some of the participants indicated that they would prefer to have wider descriptions of tasks, and several users declared the need to have the tasks read by the teacher. On the part of the players, however, it was not an obstacle to complete all the tested tasks one after another. An additional advantage mentioned by almost all participants was the possibility of simultaneous cognitive-motor training. Moreover, they became more positive after the first exposure to a virtual-reality system. It is a very promising result, which demonstrates that VR systems could be widely used among the elderly for comprehensive training.

Cognitive-motor tasks

The analysis of cognitive-motor tasks questionnaires showed that, in general, most tasks were positively evaluated. Despite the positive results, several issues could be improved during further evaluation. As shown in the reports obtained from cognitive-motor tasks and the qualitative reports, some features could be modified. In the qualitative report, participants claimed that adding a tutorial before starting the game could be a profitable solution. Some aspects concerning the manual usage of the VR system were underlined. The participants claimed that it was hard to catch the elements, especially in the motor task. They also stated that in the cognitive-motor task added hints could make the task more readable. Doniger et al. (2018) created a virtual reality-based cognitive-motor training for middle-aged adults at high Alzheimer's disease risk. The study involved simulation of daily activities, such as a virtual supermarket. The participants reported that adding training before the exercise could be an easy-to-use solution to avoid other problems. It proves that such tutorials could contribute to the easier perception of the virtual reality system for the elderly who had no prior experience with VR. Moreover, it could resolve other difficulties concerning system usage.

Importantly, the tasks included in the training relate to daily life activities, which makes the system ecologically valid. Moreover, the usage of VR systems improves the immersion of participants. Mrakic-Sposta et al. (2018) created physical and cognitive training which included riding a bike in a park, crossing roads-avoiding cars, and making grocery shopping in a supermarket. They proved that participants showed a greater improvement in the executive test, memory, and verbal fluency functions. This evidence suggests that cognitive-motor training could prevent or slow a person's cognitive decline with age.

Future works and limitations

Virtual reality systems represent a promising technological solution that could be easily implemented as part of a cognitive-motor rehabilitation program for the elderly. Previous studies confirm that such training can result in an improvement of both motor and cognitive skills, but also support everyday functioning of older adults (Mrakic-Sposta et al., 2018; Kannan et al., 2019; Gamito et al., 2020; Faria et al., 2016). The inclusion criteria in our pilot study were the lack of cognitive impairment. However, the introduction of the VR system to clinical practice, considering both the healthy group and pathology-related complications, could have the potential for usability (Lin, Lee, Lally, Couhlin, 2018; Syed-Abdul et al., 2019). Previous research (Doninger et al., 2018; Kannan et al., 2019; Faria et al., 2016) proved that using virtual reality based-training could be widely used in patients with Alzheimer's disease risk or with chronic stroke.

Different issues related to the software have been highlighted by the participants. These topics are reserved for future work. Further studies will take into account adding a tutorial before an exercise, as suggested by the participants. One downside regarding the pilot study is that it includes a limited number of participants. In any case, the homogeneity of information obtained from the interviews permits us to hypothesize that numerous other critical variables would not affect our findings when tested with a greater number of subjects. Another potential limitation is related to the problem of cybersickness that may occur during exposure to VR environments (Cobb, Ramsey, Wilson, 1999). However, our VR tasks are designed to minimize this risk. The cognitive-motor training system presented has been proven to be well-accepted by the participants.

The results of user interface testing pointed to the need for a slight adaptation of the size of objects and the scale of the environment itself. The use of a wide-angle camera, which increases the field of view, implies the need to slightly enlarge objects that were perceived as too small in their original size. The reported problems with remote object selection (exploiting ray casting) were solved by increasing the sensitivity area assigned to the selected objects and moving them slightly away from each other. Therefore, the designed interface was received very positively.

A few users pointed to the need to implement mechanisms to calibrate the VR environment space to the averaged preferences of different users. The operation of the hardware interface (HTC Focus Plus with dedicated controllers) proved to be smooth and intuitive for the proposed scenarios. The core functionality of HTC devices was used to make the process of learning and using VR controllers as simple as possible. The ease with which the users familiarize themselves with both the hardware and the environment demonstrates its high accessibility and intuitive use.

CONCLUSIONS

The pilot study showed the advantages of the Grydsen software, while also indicating the areas that need improvement. Appropriate modifications will be made in the next stages of the project. This will help to achieve greater usability and functionality of the software presented. What is important, our pilot study showed that despite initial concerns about the virtual reality environment, the elderly responded very positively and declared their willingness to continue participation in the project.

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