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Chapter 15. SERIOUS GAME FOR PERSONALISED REHABILITATION OF THE COGNITIVE FUNCTIONS OF THE ELDERLY

15.1. Introduction

Current demographic forecasts predict an increase in life expectancy and a significant increase in the elderly population which will result in an increase in health problems in society [1]. To address the challenges of an ageing population, research and policy planning worldwide are focused on ensuring a better quality of life for older people and reducing the burden on the traditional healthcare systems. This has started a trend in healthcare to go from curative to preventive care. More emphasis has been placed on preventing or delaying the onset or progression of diseases by promoting a healthy lifestyle [2–4] and seniors' monitoring [5–8]. Cognitive functions are a set of processes thanks to which we receive information from the environment and notice the relations between them. Cognitive decline with age is inevitable, but the extent to which it occurs and the rate at which it occurs varies from person to person [14]. In general, however, the symptoms of age-related cognitive decline (ARCD) include: decreased psychomotor speed, memory and learning disorders, visual-spatial disorders, diminished spatial orientation, language disorders, executive function disorders, slower inductive reasoning, and slower problem-solving. The development of effective interventions that could maintain levels of cognitive functioning and delay cognitive and

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functional decline is critical in the field of public health. In recent years, interest in cognitive remediation techniques in the elderly has increased. Cognitive treatment to enhance cognitive functions is studied in the elderly with ARCD, mild cognitive impairment (MCI), early stages dementia (Alzheimer's disease (AD) and vascular dementia (VaD)), brain damage or disease (stroke, brain tumours, traumatic brain injury, etc.) [9, 10, 13]. There are cognitive function assessment tools for classifying various types of cognitive impairments (e.g. the Mini-Mental Status Exam (MMSE) [11]). Usually, however, they require professional medical personnel to perform the tests and a long testing time. With the accelerating development of technologies, many smart devices are used to evaluate and enhance the fitness of the elderly. In recent years, it has been common to use serious games (SG) characteristics to design cognitive function training games. SG does not take entertainment as the primary goal but is used to achieve learning purposes. Research showed that SG training could improve the players' cognition, coordination, behavioural, and psychological symptoms [10]. Computer-based tools can also be used as one of the primary screening tools for the cognitive function of the elderly [11–13]. There are also studies concerning the relationship between fitness and cognition. The research results suggest that fitness training can enhance cognition [14]. Also, reduced balance ability due to ageing has been reported to be associated with cognitive functions and slowing central information processing speed [15].

The aim of this work is to evaluate the SG supporting the process of rehabilitation of cognitive functions of the elderly while activating them to move by introducing motion control of the application. The presented tool uses automatic adjustment of game levels to personalise the difficulty of tasks performed by players. The authors present preliminary tests carried out with the participation of seniors aged 70–79.

15.2. Serious game "Catch me!"

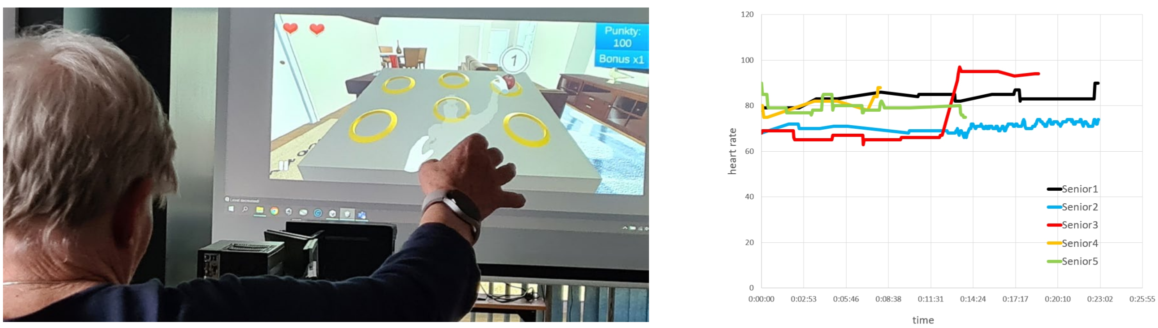
15.2.1. Aim of the game

The created serious game supports the rehabilitation of the cognitive functions of a broad group of elderly with cognitive impairment. Additionally, the game activates older people to move by using a motion control of application (upper limbs movement). By playing, the elderly can maintain (or even improve) their cognitive and physical functioning levels and delay psychophysical decline. The proposed game can help the elderly with ARCD, MCI, early stages dementia, brain damage or disease. The requirements for the player are the ability to manoeuvre the upper limbs, the basic ability to process visual data and the basic ability to analyse information. The authors did not impose a position on the user during the game. Standing is recommended but not required to add to the physical intensity of the game. Users are allowed to sit while playing.

15.2.2. Game description

During the game, players are supposed to recognise collectable/non-collectable objects appearing on the game scene and select collectable while ignoring non-collectable (Fig. 1a). Selecting an object consists of keeping your hand on the object for a specific time. The game uses the Azure Kinect 3D's depth camera to recognise the player's motion for game control and seniors' behaviour monitoring.

The game scene has a console with six holes, from which three-dimensional objects slide out in random order. At the moment, 38 objects belonging to 4 categories have been prepared: sports, food, dishes, and electronics. At the beginning of the game, the category of objects is randomly selected, and the player is informed what kind of objects to collect. Items belonging to a given category are set as collectable, belonging to the other three categories – non-collectable. Additionally, one more game level, "Very Easy", has been added, where the player selects the green cuboids and skips the red cuboids. This level was added for people who have problems with recognising categories.



(a) (b)

Fig. 1. Testing of the game "Catch me!" (a) and seniors' heart rate during gameplay (b)
Rys. 1. Testowanie gry „Złap mnie!" (a) i tętno seniorów odnotowane w trakcie rozgrywki

For each correct choice, the player receives points multiplied by the bonus value for a series of correct selections. If the player does not get a newly appearing collectable object, the bonus value is reset to 1. When the player selects another correct object, the bonus value is increased by 1 (at most to 5). For example, after collecting all four collectable objects that appeared in succession, the bonus value is 4. If the player chooses a non-collectable object, they lose one heart. At the beginning of the game, the player gets three hearts. The player also loses one heart if they fail to select ten correct objects in a row. The game ends when a player loses all three hearts or when the assigned time limit (10 minutes) is reached. Information about the time remaining to the end of the game appears for the last 60 seconds. Thanks to this, the user cannot feel time pressure for most of the test and can focus on the task.

The player starts the game on one of five difficulty levels of their choice: "Very Easy", "Easy", "Medium", "Hard", and "Very Hard". In the first level, there are only two types of objects: green cuboids – collectable, and red cuboids – non-collectable. Three-dimensional objects from the four presented categories appear on the next levels. The levels differ in: the number of collectable and non-collectable objects, the frequency of appearance of collectable and non-collectable objects, the interval between the appearance of successive objects, the time the objects stay on the scene to be selected, the time needed to select an object (holding your hand over the object). As the game progresses, the difficulty level is automatically lowered when the player loses a heart. Once a certain number of points are earned, the player is upgraded to a higher difficulty level.

15.2.3. Technology and tools

Microsoft's Azure Kinect 3D device is applied for tracking and capturing movements with a 3D vision sensor and artificial intelligence algorithms. The device maps depth using structured light, performing real-time calculations. Azure Kinect SDK is a set of development tools that enable image processing, detection of the position and movement of the user's skeleton and body, and speech recognition. The following SDKs of the Azure Kinect DK development environment were used in the project:

- Sensor SDK for low-level sensor and device access.
- Body Tracking SDK for tracking bodies in 3D – providing body segmentation and access to an anatomically correct skeleton for any part or entire body within the

camera's field of view. In the game, the position and rotation of each user's joint in relation to the device are obtained, as well as information, in the form of an image on pixels assigned to a detected body.

The following project tasks are accomplished with the captured data:

- Motion control of virtual 3D objects simulating the body segments of the character.
  The joints of the character's skeleton (e.g. right or left hand) are assigned to three-dimensional objects in the virtual scene. As a result, the object representing the joint on the screen moves in a manner similar to the selected segment of the user's body. To properly control a given virtual object, it is assigned boundaries that limit the movement of the 3D object. These limits are mapped to the minimum and maximum deviation of the base joint from the control joint defined for each simulated segment (e.g., right hand base joint can be right shoulder, steering joint – right wrist). Controlling a virtual body segment boils down to detecting collisions of this object with other 3D objects of the virtual scene and responding to collision events.
- Measuring the distance of the player from the device.
  Four possible outcomes are defined: too close, too far, perfect, and undetected. The distance is measured from the position of the character's pelvis to the camera.
- Monitoring and recording the motion of players during the game.
  When checking the collision of simulated body segments with objects in the virtual scene, information about each joint (its name, position and rotation relative to the device's camera) is recorded.

Unity game engine was used as the development environment. It allows the creation of interactive 2D and 3D games and other interactive experiences such as virtual reality (VR) and augmented reality (AR) applications. Unity provides a comprehensive set of tools and features that facilitate the entire game development process. The C# language enables developers to write custom code to implement game mechanics, behaviour, and interactions.

15.2.4. Rehabilitation tool for the elderly.

As part of the project, the requirements and limitations of the elderly, as the target recipient of the project, were identified. The limitations of seniors have been divided into physical, cognitive and social. The following physical and cognitive limitations (L) have been addressed in the design of the game (G):

- L: Auditory limitations including impaired hearing, the occurrence of tinnitus, and the occurrence of speech understanding disorders in noise.
  G: Sound effects have been abandoned in the game, assuming that players will have the basic ability to process visual data, and sound information can be distracting and disorientating.
- L: Greater fatigue, an impaired adaptation of the circulatory system to the increased effort as well as disorders of the balance apparatus and occurrence of dizziness.
  G: Standing is recommended but not required to increase the physical intensity of the game. Users can sit while playing.
- L: Motion limitations including reduced overall mobility, reduced range of motion, reduced level of orientation in determining the position of individual parts of the body, and weaker eye-hand coordination.
  G: The game encourages the movement of the upper limbs, testing the range of motion by selecting objects in various areas of the console and practising eye-hand coordination by mapping the player's hand movement on the screen.
- L: After a stroke the hemispatial neglect syndrome may occur, belonging to the category of neuropsychological disorders of attention, manifested by the failure to notice objects on one side of the patient's body.
  G: The game allows detection of the disorder by observing the player's reaction to objects appearing on one side only.
- L: Cognitive limitations including decreased psychomotor speed, memory and learning disorders, visual-spatial disorders, diminished spatial orientation, language disorders, executive function disorders, slower inductive reasoning, and slower problem-solving.
  G: Operation of the game includes: slower, subdued game mechanics, a limited number of stimuli, and the amount of information provided by the game and only the necessary functionalities.

Following cognitive impairments have been identified as those that can be remedied in the proposed game:

- a short-term episodic memory disorder,
- learning disorder,
- executive functions disorder,
- attention and concentration disorder.

It is accomplished by remembering by the player the category of objects to collect, distinguishing objects, reacting appropriately to the appearance of the “correct” objects and ignoring the “wrong” ones. Moving the limbs to select an object requires the player to analyse information, decide on further actions and perform a specific activity. All this must be done within a limited time.

It is important to remember that older people are not a homogeneous group but are characterised by diverse skills, needs and limitations. Because of that, it is necessary to personalise the game's difficulty. Five game levels are defined in the game, requiring different cognitive abilities. In addition, as the difficulty level increases, the time needed for the player's reaction decreases, which is associated with greater physical demands. At the beginning of the game, the player determines his skill level by selecting the corresponding game level. However, the player may not know his level or make a mistake when choosing. In this situation, the level increases or decreases based on the player's performance. In addition, it is possible to make small changes to the game's difficulty level by fine-tuning parameters within a given level (e.g. increasing the number of collectable objects) without changing the level while observing the ongoing results of the players.

In order to be able to tune the game to the player, provide the player with a game summary and analyse the results obtained to evaluate the player or group of players, it is necessary to implement an appropriate monitoring system within the game. During the game, players' behaviour and results are monitored and saved in external files. For our project, the following data was selected for recording:

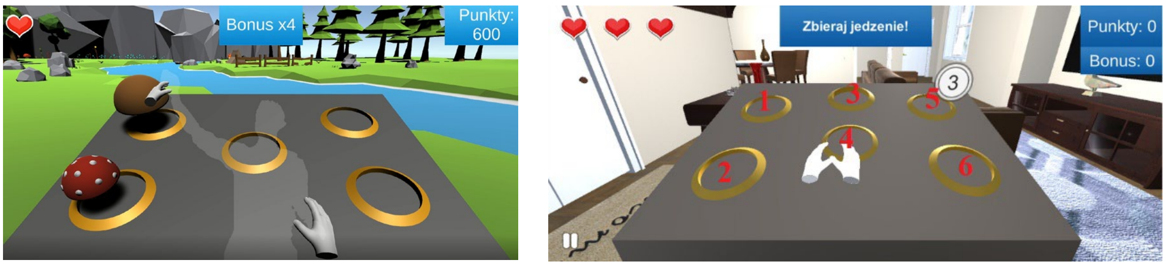
- Motion data.
  During the game, when checking for collisions of simulated body segments with objects in a virtual scene, information about each joint is recorded (its name, position and rotation relative to the device's camera).
- Gameplay data.
  During the game, information about the selected objects is recorded: the name and category of the object, whether it was collectable or not, from which hole in the console it slid out, and how many points the player got for it. Information about the player's difficulty level, level change, bonus reset and heart loss is also recorded. During the recorded events, information about the current number of hearts and the number of points scored by the player is also saved. For each recorded event, the time of the event is logged.

The recorded data allows the analysis of the quality of the game parameters and the physical and intellectual condition of the players. Collecting the above data for each player in subsequent periods allows the diagnosis of deterioration or improvement in the players' health. Based on the saved data, it is possible to reconstruct the player's movements and their analysis (e.g. range of mobility of selected joints). We can determine the speed at which the players analyse information and their reaction time. We can assess the state of the player's cognitive functions.

15.3. Game evaluation

15.3.1. Game design process

The development of the game was an iterative, user-centred process carried out by an interdisciplinary team of supervisors and students of the Faculty of Automatic Control, Electronics and Computer Science, the Faculty of Biomedical Engineering, and the Faculty of Architecture of the Silesian University of Technology, supported by external medical experts from Geriatric Hospital in Katowice and volunteer seniors.
The project was carried out in three phases. The objective of the first phase was to develop a prototype solution based on consultations with seniors, medical personnel and literature studies. During the second phase, the solution was iteratively tested with project participants (aged 19–20) to identify universal problems limiting the quality of the game and issues with player behaviour monitoring. Consultations with seniors and medical personnel were also conducted. Both expert knowledge and lessons learned from testing were used to refine the solution. In the third phase, the game was tested by seniors. The prototype game was developed as the result of the project “PBL as part of the program Excellence Initiative – Research University” titled “The use of artificial intelligence sensors in the rehabilitation of the cognitive functions of the elderly”. The prototype was then tested and refined as part of the project “PBL as part of the program Excellence Initiative – Research University” titled “Testing the possibilities, limitations and preferences of seniors when using modern IT tools”.



(a) (b)

Fig. 2. A screen of prototype game (a) and game after changes with numbered console holes (b)
Rys. 2. Ekran prototypu gry (a) i gry po zmianach z ponumerowanymi otworami konsoli (b)

The first phase resulted in the development of a prototype game [13]. During phase two of the design process following problems (P) were identified and addressed (A):

- P: The camera motion in the main menu is disorienting (too fast) and distracting.
  A: Camera motion in the main menu has been significantly slowed down, and the background has been simplified to provide less distraction from option buttons.
- P: In the game prototype, the scene background and collectable objects could cause additional confusion for the urban elderly due to it being a foreign environment: a rocky forest area with forest objects (Fig. 2a).
  A: In response, the background was changed to an apartment and items from the life of seniors (e.g. dishes) or commonly recognisable items (e.g. laptop, boxing glove) were chosen for selection (Fig. 2b).
- P: Determining the difficulty of a level based on the category of selected objects is problematic because it depends on the player's knowledge and experience.
  A: The category of objects is determined randomly at the beginning of each game, providing variety without imposing level difficulty.
- P: Lack of a reaction to not selecting a large number of collectable objects.
  A: The player loses one heart if he fails to select eight correct objects in a row.
- P: Difficulty levels do not take players' response time into account.
  A: The levels differ in the interval between the appearance of successive objects, the time the objects stay on the scene to be selected, and the time needed to select an object.
- P: The number of non-collectable objects is constant for all difficulty levels.
  A: The levels differ in the number and frequency of appearance of non-collectable objects.
- P: The collision boxes defining the selection areas of the selected objects are too small – they do not cover the whole objects.
  A: The collision boxes cover the whole objects.
- P: The lack of a time limit for a single game makes it difficult to compare games (e.g. whether the game was finished due to physical fatigue or boredom).
  A: A time limit (10 minutes) has been set for a single game.
- P: Gameplay data is saved after the game ends, which summarises the game but does not allow monitoring of the player's behaviour during the game.
  A: Player and game events are recorded during the game.
- P: There is no adjustment to the player's skill once the game level is selected.
  A: The difficulty level is automatically decreased or increased depending on the player's performance.

The second phase resulted in refining the game, which volunteer seniors then tested in the third phase. The results were compared with the results of tests carried out by young people (aged 19–20) and young people in a suit simulating old age.

15.3.2. Game testing process

The project's third phase included the process of initial testing of the game with the participation of volunteer seniors. During the tests, additional tools were used to evaluate the game:

- Surveying.
  The survey concerns the feelings of seniors after participating in the testing process. It asks about the overall impression of the game and the degree of its transparency (distinguishability of objects, level of complexity of the rules). In addition, it also tries to determine the degree of usefulness of the created application in the rehabilitation process.
- Smartwatch Samsung Galaxy Watch 4.
  Information on the senior's heart rate can significantly expand our knowledge of the senior's physical condition during the gameplay. The heartbeat becomes faster when people are active, excited, or scared and drops when they are resting, calm, or comfortable. Furthermore, heart rate depends on a person's age and overall health. Therefore, a "normal" heart rate varies from person to person, but for most healthy adult women and men, resting heart rates (when they are at rest and their heart is pumping the lowest amount of blood to supply the oxygen their body needs) range from 60 to 100 BPM (beats per minute). The rate at which the heart beats when it is working its hardest is a maximum heart rate and can be roughly calculated from a person's age (that is, 220-age).
  Smartwatches and fitness bands measure heart rate by scanning blood flow near a wrist with green LED lights paired with light-sensitive photodiodes that illuminate the skin and measure changes in light absorption. Smartwatches are less accurate than professional medical equipment. However, they can be close and let an individual monitor their heart rate while walking, running, cycling, or exercising.
- Suit simulating old age.
  The age-simulating suit was used to compare the performance of seniors with young people (students) wearing it. The suit is designed to simulate the physical limitations of the elderly. It consists of a set of weights and restraint straps placed on the chest, neck, elbows, wrists, knees, and feet, respectively. In order to fully exploit the

potential of the suit, the students climbed the stairs several times after putting it on, which caused them to feel tired, thus increasing the effect simulated by the costume.

The testing process involved five seniors (3 women, 2 men) aged 70 – 79 in good physical and mental health and two students (woman, man) aged 19 – 20 wearing a suit simulating old age and without a suit. All participants except one (senior1) were right-handed. All tests were held standing, 3–5 meters from the Azure Kinect camera. Each game started with a "Medium" level, which progressively changed depending on the player's skills. The seniors and students were informed about the tools used in the study and its purpose. After all information was provided, the seniors and students agreed to participate in the study.

15.3.3. Results

Table 1 presents a comparison of the results of seniors (s), students (st), and students wearing age suit (sts). The following average values for a single game were compared: the number of hearts lost (ht), the number of collected objects (no), the hole with the most frequently selected objects (hb), the hole with the least frequently selected objects (hw), game time in seconds (gt), average heart rate (hr), absolute rise in heart rate (hri).

Table 1

Game testing results

	s1	s2	s3	s4	s5	st1	st2	sts1	sts2
ht	3.0	2.7	3.0	3.0	2.0	0.0	0.0	2.0	1.0
no	18.0	54.0	13.5	21.0	34.5	68.0	68.0	62.5	60.5
hb	2	6	4	6	4	3	4	6	2
hw	6	1	5	1	2	2	1	3	3
gt	269.0	403.0	210.0	353.0	452	576.0	577.0	591.0	582.0
hr	84.0	70.8	74.7	80.9	79.5	117.0	108.0	115.0	141.0
hri	12.0	6.0	35.0	10.0	15.0	5.0	2.0	6.0	3.0

Elderly people are more likely to lose hearts than young people. According to the observations made during the measurements, most hearts were lost due to not collecting "good" objects. Losing hearts by collecting "bad" objects was very rare. During most games, seniors lost three hearts, which resulted in a premature end to the game. It was noticed that young people, after wearing a suit simulating old age, showed a greater tendency to lose hearts. During the game, a change in the difficulty level for players could be observed. Seniors moved primarily to the "Easy" level and students to the "Hard" level.

The console hole that was selected the least often was located at the top, on the left side of the console, while the most often, the respondents chose holes numbered 4 and 6 (Fig. 2b). The exception was senior1 (left-handed), who preferred hole numbered 2, and least often selected objects from hole number 6.

Figure 1a presents values of the heart rate of seniors during the gameplay. Playing the game in each case resulted in an increase in the measured heart rate, wherein in most cases, this increase in seniors was higher than in students. Surveys at the end of the tests indicate that seniors did not perceive the gameplay as "tiring". As the main problems during the game, seniors indicated keeping their hands steady over the object for the recommended time (to select it) and difficulty coordinating hand movement with their virtual counterparts. Students did not report problems with keeping their hands in one position or with the coordination of virtual hands. However, after wearing a suit simulating old age, they indicated increased difficulty in the above activities. The difficulty level of the presented game was described as easy by 40% and moderate by the rest of the surveyed seniors.

When asked about possible improvements to the game, seniors indicated, in particular, the change of virtual hands to more precisely synchronise the position of the selected object and the hand.

All the surveyed seniors stated that if they had the opportunity, they would use a form of rehabilitation using modern technologies. Each of them would also recommend this type of rehabilitation to their friends.

15.3.4. Discussion

When analysing the obtained results, one should be aware of the limitations resulting from the small group of participants and that the participants represent seniors with mild ARCD. Further testing is needed, especially among people with more apparent cognitive disorders, to assess the cognitive aspect of the game in more precision. The current results are primarily about the game's physical demands (this is evident by the fact that seniors could easily recognise "good" objects). Conducted tests still allow for an initial evaluation of the game from the point of view of older people.

Seniors have a higher tendency to end the game by losing hearts than by the time allotted. The fact that the students could compensate for its effect after wearing the suit simulating old age, and as a result – persevere until the end of the game indicates the deterioration of hand-eye coordination and the ability to adapt it with age. In addition, it may indicate that the players' results are influenced by non-physical aspects, such as attention and concentration, and the speed of analysing information, which are not affected by the suit. Seniors' difficulty levels indicate the need to lower the game difficulty for all programmed levels to allow older people to move between more difficulty levels, not just the easiest.

The preference for collecting objects appearing in the lower holes may prove the deterioration of motor skills and the difficulty in keeping the arms raised stably, which could be slightly noticed during the tests of students in the age suit.

The elderly did not perceive the game as “tiring”, and at the same time, their physiological parameters recorded during the game suggested increased physical activity (increased heart rate). The game engaged seniors to an appropriate degree in terms of motion, forcing users to exercise. At the same time, the elements of gamification meant that it was not perceived as “intrusive” but motivating and even entertaining.

15.4. Conclusion

In this paper, we presented a serious game for elderly people supporting cognitive rehabilitation, using motion control of cognitive tasks to motivate older people to move. The game was initially evaluated by seniors aged 70–79. The results of the tests indicate that the game allows to determine the psychophysical skills of the elderly by activating them to perform cognitive and physical tasks. Monitoring players' behaviour and results makes it possible to personalise tasks to players' skills. The conducted research showed, however, the need for less effort in the physical aspect of the game, particularly reducing the time needed to select objects. It is also necessary to conduct additional research with seniors showing more signs of cognitive disorder to refine the cognitive tasks of the game.

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SERIOUS GAME FOR PERSONALISED REHABILITATION OF THE COGNITIVE FUNCTIONS OF THE ELDERLY

Abstract

The world's population is ageing rapidly, putting a heavy strain on traditional healthcare systems. Developing effective interventions that can maintain the functioning of older people and delay their decline is critical for public health. The aim of this work is to evaluate a serious game supporting the process of rehabilitation of cognitive functions of the elderly while activating them to move by introducing motion control of the application. The presented tool uses automatic adjustment of game levels to personalise the difficulty of tasks performed by players. The authors present preliminary tests carried out with the participation of seniors aged 70–79.

Keywords: cognitive function rehabilitation, elderly, serious game, depth camera