Multiple Sclerosis Rehabilitation With Use Of Virtual Reality

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Abstract

The current article includes a description of current solutions (SLR) and suggestions for rehabilitation exercises that could be used to treat cognitive impairment in multiple sclerosis disease in a virtual reality environment. The product of the research work is a set of 30-second rehabilitation games in a VR environment, which were tested on potential users.

1 Project overview

The project's aim was to create a package of VR applications/games that would test executive and visual-spatial functions, and also visual-spatial and verbal memory in patients with cognitive impairment. Applications should contain tasks and instructions in Polish, increasing levels of difficulty, and data on the speed, correctness and response time of tasks. The duration of such a game should not exceed 30 seconds.

2 Illness overview

The application should help patients with cognitive impairment (Multiple sclerosis) develop their functions and memory by playing the games, which gives them a possibility of coping with their illness in a more pleasurable way. Instead of repeating dull exercises, patients are provided with a new way of rehabilitation - a set of virtual reality games which develop their executive and visual functions, but also improves visual and verbal memory. Each game is built to provide a pleasurable experience and thanks to randomization introduced in the games, a player can enjoy them differently almost every other time. Playing games instead of executing rehabilitation exercises and gaining the same amount of improvement creates a possibility of introduction of a new era in medicine, which could totally change the way we look at rehabilitation now.

3 Systematic Literature Review *SLR*

3.1 SLR Execution plan

The goal of the SLR was to find the answers for the question: are VR apps effective tools to train spatial-cognitive abilities. If so, what would be the effective ideas of rehabilitation games which would use the full potential of a modern VR set. In the context of rehabilitation it is meant to work with patients who mostly suffer from multiple sclerosis.

3.1.1 Keywords used

VR, virtual reality, rehabilitation, training, SM(sclerosis multiplex/multiple sclerosis)

3.1.2 Search string

A. ("VR" OR "virtual reality" OR "augmented reality")

B. ("rehabilitation" OR "training" OR "therapy" OR "treatment")

C. ("spatial" OR "cognitive" OR "cognition" OR "sight")

D. ("multiple sclerosis" OR "SM")

E. Final search string: A AND B AND (C OR D)

3.1.3 Literature databases

SpringerLink, Scopus, IEEEXplore, ACM Digital Library, PubMED, PubMED Central

3.1.4 Inclusion criteria

- Articles presented on conferences and magazines published between 2005 and 2021.
- Articles published in English.

3.1.5 Exclusion criteria

- Articles strictly connected to other article (such as extended versions or erratas).
- Articles presenting applications used in monitoring the rehabilitation process.

3.1.6 Quality criteria

- Research based on prototype application.
- Games scenarios for rehabilitation.
- Code guidelines and suggestions about creating an application.

- Description of the effectiveness of given rehabilitation.
- Comparison with different types of therapy.

3.1.7 Data extraction

- Level of rehabilitation's effectiveness.
- Ideas for application.
- Development guidelines and suggestions.

3.1.8 SLR Process

1. Definition, verification and approval of the plan.
2. Construction and validation of the search string.
3. Searching databases using search string and inclusion criteria.
4. Phase I selection based on titles and abstracts.
5. Phase II selection based on the content of the article and exclusion criteria.
6. Evaluation of quality criteria.
7. Final selection of articles based on the article's quality.
8. Snowball - Overview of the referenced materials in selected articles.
9. Extraction of knowledge from each article that passed the final selection.

3.2 SLR Results [1–25]

3.2.1 Results in numbers

Table 1: SLR results in numbers

Stage	Springer-Link	Scopus Scopus	IEEE-Xplore	ACM Digital Library	PubMed	Pubmed l Central
Search for a phrase	48038	12000	873	6352	1737	19035
Titles and abstracts	25	8	56	70	44	127
Data extraction	0	0	10	5	2	8

3.2.2 Articles selected for data extraction

Table 2: Selected articles

Article	Application (Disease)	Device	Game Engine	Number of Games	Participants
[1]	Multiple sclerosis	Desktop	No Data	7 (basic) + 3 (advanced)	8
[2]	Stroke	Oculus, HTC Vive	No data	1 (3 levels)	No data
[3]	Neurological problems	Microsoft Kinect	No data	3	12
[4]	Physical and cognitive rehabilitation	No data	Unity	8	No data
[5]	Spatial short-term memory problems	Tablet, Desktop	Unity	1 (2 phases)	53
[6]	Stroke	Microsoft Kinect	Unity	4	14
[7]	Stroke	HMD, CAVE (3 displays)	Renderware	2	20
[8]	Spatial functions	Oculus Rift, Leap Motion sensor, Two wooden blocks	Unity 5.3 (programmed with C)	2	52 (Pilot study - 6)
[9]	Stroke	Asus VG236H 3D monitor, nVidia 3D Vision glasses	Unity 3D Pro	4	No data
[10]	Stroke, Alzheimer's disease	HTC Vive	No data	6	6
[11]	Stroke	No data	No data	6	45

[12]	Stroke, Cognitive dysfunction	24 inch touch screen, Microsoft Kinect Sensor, Tobii Eytracker T120	No data	3	11 chronic stroke patients
[13]	Mild cognitive impairment or Alzheimer	Oculus Rift	No data	1	45
[14]	Mild cognitive impairment or Alzheimer	HTC Vive, Microsoft Band	Unity	No data	No data
[15]	Unilateral spatial neglect	FOVE Eye Tracking	No data	2	No data
[16]	Stroke	No data	No data	8	35
[17]	Mild cognitive impairment	Oculus Rift, EEG headset	Unity	8	30
[18]	Stroke	42" touch screen	No data	1 (7 task)	21
[19]	Mild cognitive impairment	HTC Vive	No data	6	21
[20]	Stroke	Camera, custom handle with tracking	No data	1	24
[21]	Stroke	Microsoft Kinect	Unity	3	15
[22]	Multiple sclerosis	Desktop	No data	No data	26
[23]	Mild cognitive impairment	HTC Vive, Microsoft Kinect	No data	3	34
[24]	Cognitive impairment	No data	No data	3	30

[25]	Cognitive training	Oculus Go + Controller	Unity	1	29

3.2.3 SLR Comments

At the beginning of the information searching process we hadn't had enough medical knowledge that could let us precisely classify the usefulness of the articles. As the gathered materials were hardly ever describing use cases of people suffering from multiple sclerosis, we decided to expand our research to other diseases - these which were found in search results most frequently. These were mostly strokes, Parkinson's disease, Alzheimer's disease, dementia and neurocognitive disorders. In the second phase of documents filtering stage we were able to notice the analogy between the rehabilitation exercises of each disease and we could reject those, who were strictly connected with kinesthetic function and memory.

3.2.4 Extracted data

In extracted articles 32 rehabilitation games scenarios have been found. Presented games scenarios were created by authors from scratch, created based on simple existing games, but transferred to VR and third dimension, and also existing games used for the sake of rehabilitation. The articles explored various aspects of rehabilitation using VR. Research results differ between articles, the problem may be the lack of standardization of the method of research. In articles where it was mentioned, the most common engine was Unity, and the most frequently used vr devices were hmd sets from various manufacturers. The question about the efficiency of the VR games as the rehabilitation tool in comparison to traditional tools was left unanswered, which shows a research gap in this field. VR technology has seen extreme popularization and development in recent years due to it becoming more accessible. Since this technology as we know today is quite fresh, there aren't many tested implementations and ready-made solutions, which opens the possibility for innovative research and development in this branch.

4 Games development process in collaboration with Medical University of Gdansk

Traditional rehabilitation of cognitive function for patients with multiple sclerosis, is mainly based on performing sets of tasks on paper, computer or mobile device, and thus solutions are available for two-dimensional space. As the aim of the project was to design and create exercise sets for VR goggles, the tasks had to be transferred from two-dimensional space to three-dimensional space. Due to the lack of adequate knowledge of the research group in the field of cognitive disorders treatment, the exercise proposals were not created by the research group from scratch, but they were a certain interpretation of the available solutions, and all proposals for modifying traditional exercises into a three-dimensional game form were consulted with specialists from the Medical

University of Gdansk. After discussions, possible corrections and final acceptance of each proposal by the specialists, each game was implemented.

5 Users tests

The games were tested by a group of interested individuals. Below will be presented the process of conducting the experiment and the average survey results for all games. The games were made available to the participants of the study. Users had the opportunity to play the games in order to get familiar with them and test them. Then they were provided with forms that asked them a few questions about the game they had just played. A separate form was prepared for each game, but the questions were the same in each survey.

The participants in the experiment were mixed in terms of sex (Fig. 1) and age (Fig. 2).

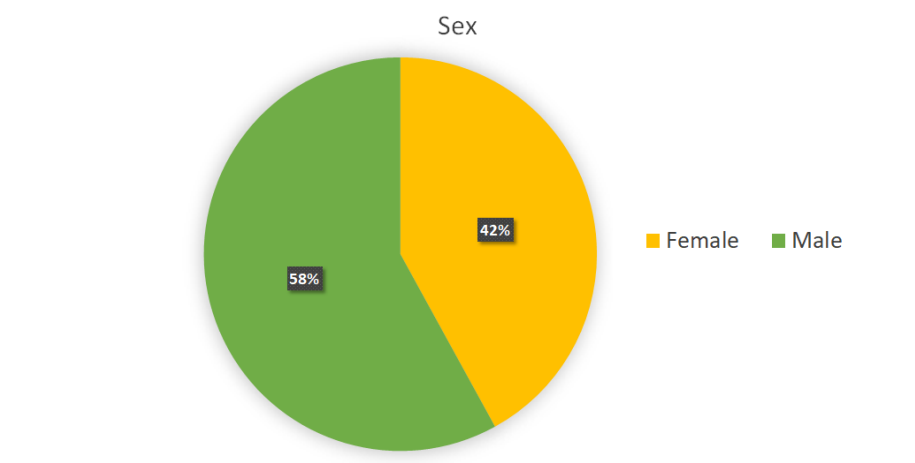

Figure 1: Distribution of respondents by sex

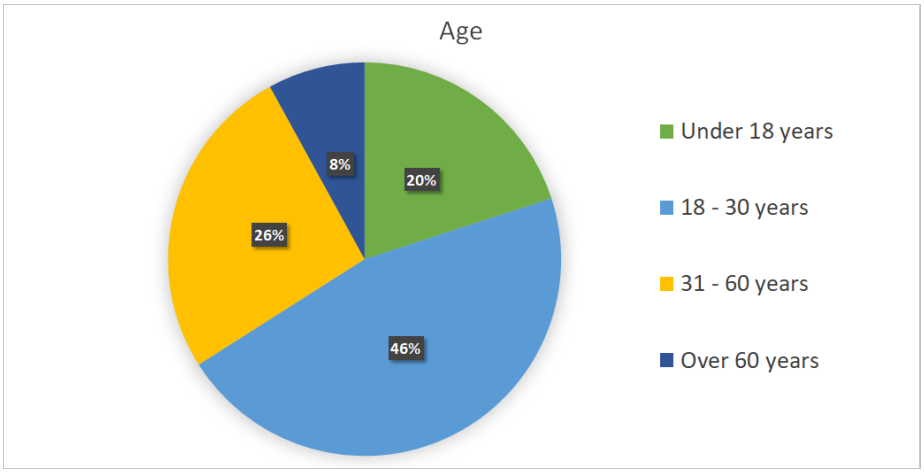

Figure 2: Distribution of respondents by age

In each survey participants were asked the following questions:

1. How do you perceive the game as a whole?
2. How would you rate the visual aspect of the game?
3. How would you rate the controls in the game?
4. How would you rate the sound in the game?
5. Are the levels of difficulty appropriately balanced?
6. Do you think the game can have a positive effect on the user's verbal memory training?
7. Do you think that the game can have a positive impact during verbal memory training by users with MS (Multiple Sclerosis)?

Participants could answer the questions using either a four-point or five-point scale, depending on the question. Additionally, a "No opinion" response was available for each question.

The average opinions for all games were generally positive, since in questions 2 (Fig. 4), 3 (Fig. 5) and 4 (Fig. 6) the opinions of the majority of people surveyed were positive or neutral. In questions 1 (Fig. 3), 5 (Fig. 7), 6 (Fig. 8) and 7 (Fig. 9) the opinions were overwhelmingly positive.

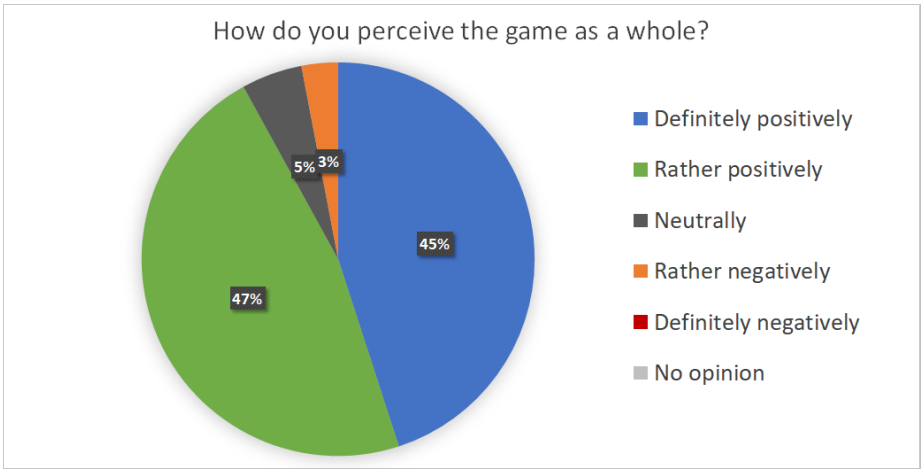

Figure 3: Chart of the distribution of answers to question 1

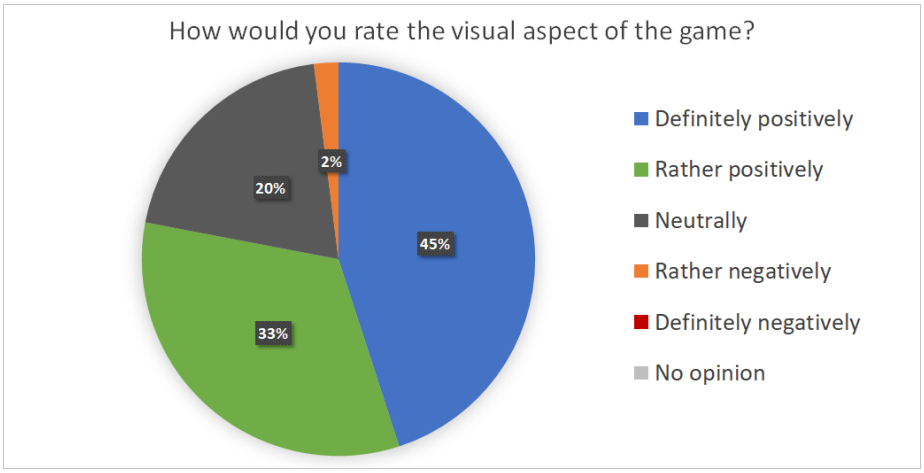

Figure 4: Chart of the distribution of answers to question 2

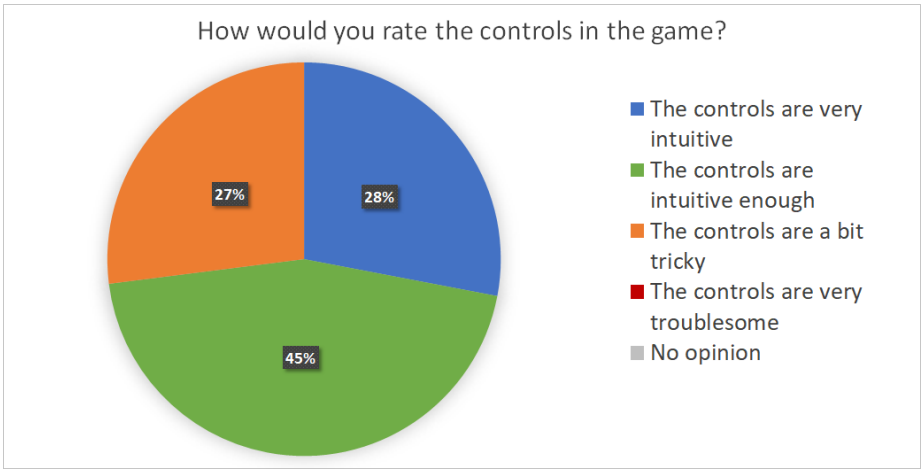

Figure 5: Chart of the distribution of answers to question 3

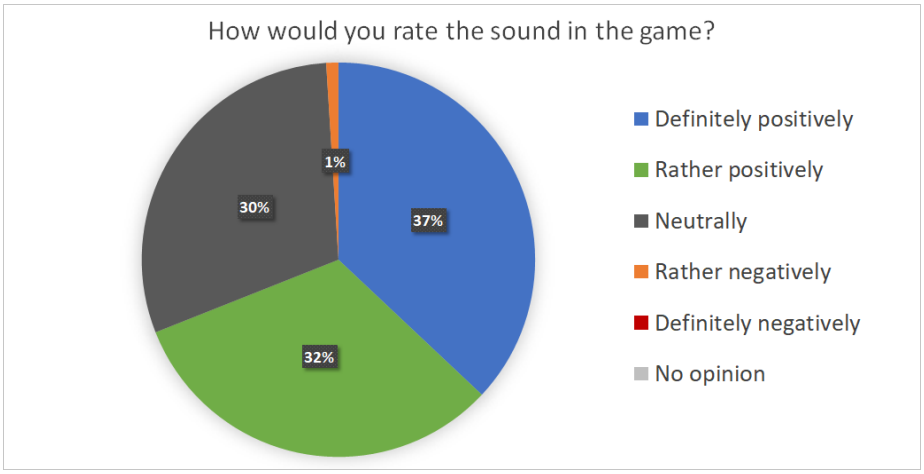

Figure 6: Chart of the distribution of answers to question 4

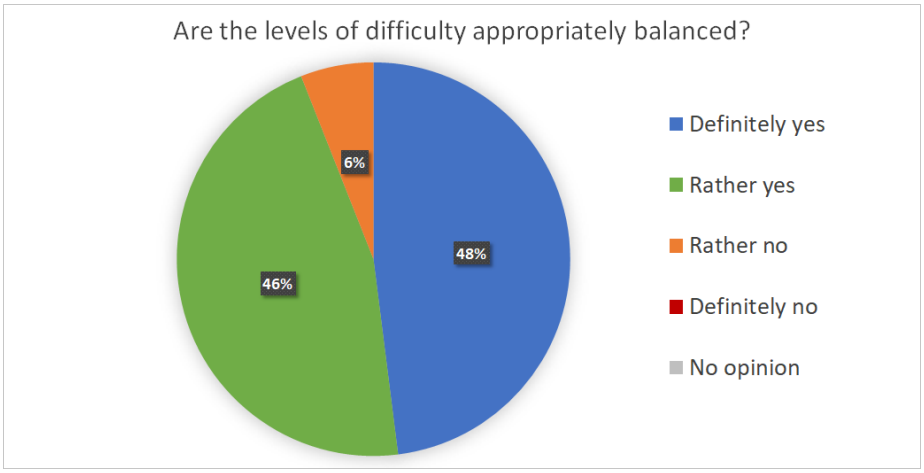

Figure 7: Chart of the distribution of answers to question 5

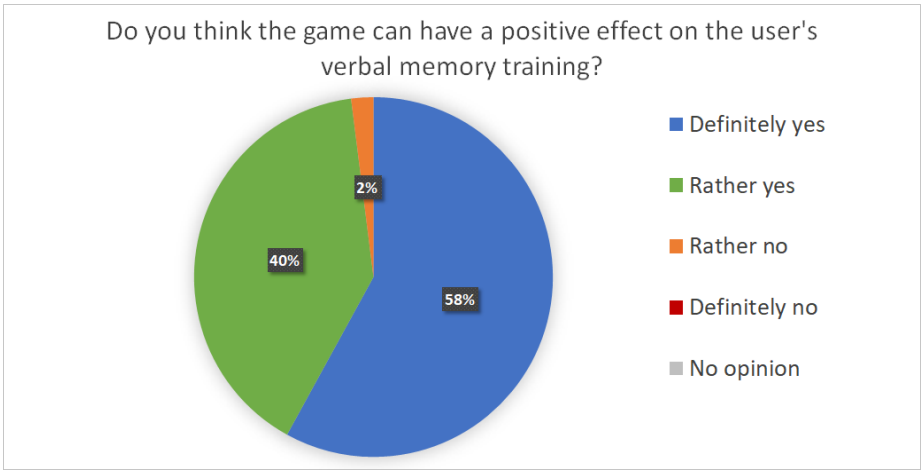

Figure 8: Chart of the distribution of answers to question 6

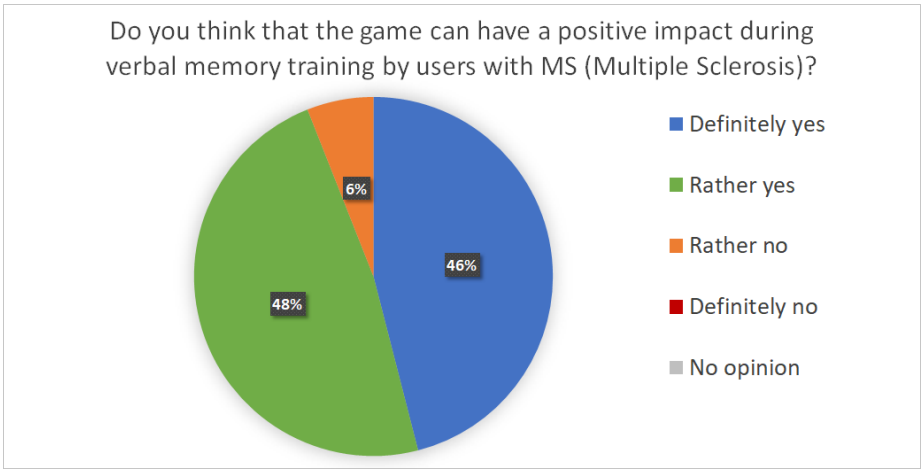

Figure 9: Chart of the distribution of answers to question 7

6 Games

6.1 Executive functions

6.1.1 Flashlight

Figure 10: Flashlight game: the player follows a mannequin

- **The main idea:** The flashlight is in front of the player, the player can grab it and manipulate it in order to follow a character. The characters move randomly around the darkened room. An example of how the scene looks during gameplay is shown in Fig. 10.
- **Increase of difficulty:** The minigame has 4 difficulty levels. As the difficulty levels increase, there are more non-criminal characters in the room and they move faster.

- **Counting player score:** The more accurately the player points the flashlight at the criminal's face, the better. After 30 seconds of gameplay, two scores are displayed in front of the player: the first is the average distance of the flashlight's light from the target (the smaller the score, the better), while the second score is the player's percentage accuracy, i.e. how much time they kept the flashlight on the criminal's face.
- **Variety of gameplay:** With each game, the appearance of the characters changes, i.e. they are randomly assigned meshes. Characters do not move along a predefined track, but between randomly placed points, which makes it very unlikely that in two games one of the characters will follow the same path.

6.1.2 Evidences

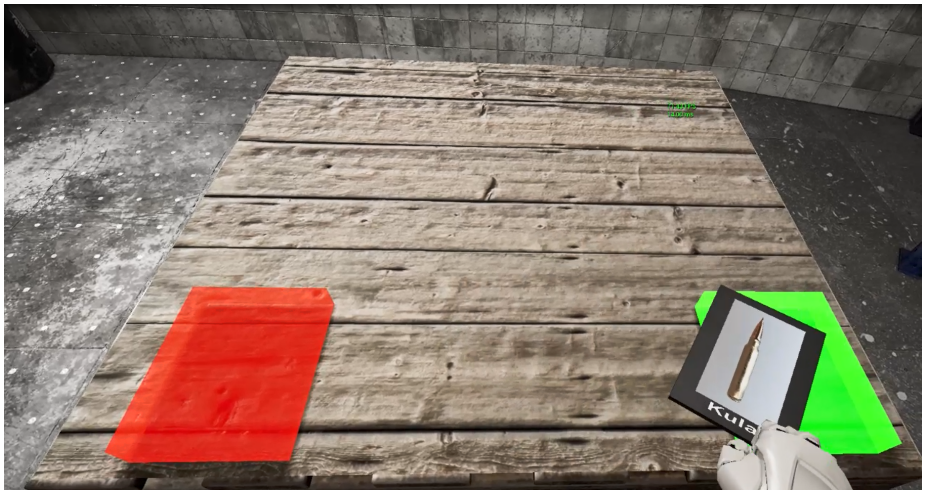

Figure 11: Evidences game: the player correctly classifies correctly captioned picture

- **The main idea:** On the table in front of the player, randomly appear pictures of supposed murder tools (evidence), which can be correctly or incorrectly captioned. The player can grab the evidence and put it back in the appropriate places (green border for correctly captioned pictures and red border for incorrectly captioned pictures). An example of how the scene looks during gameplay is shown in Fig. 11.
- **Increase of difficulty:** The difficulty level of the game can be adjusted using two parameters. The first one is responsible for the number of pieces of evidence the player has to classify within 30 seconds. The second is optional and allows to set the time in which the player must classify a single piece of evidence. If the player does not classify the evidence within the given time, the evidence is destroyed.
- **Counting player score:** The player is rewarded one point for correctly classifying an evidence. The maximum number of points is equal to the

number of pieces of evidence. If the player makes a mistake or fails to put the picture back in time, he loses the opportunity to score a point for that evidence.

- **Variety of gameplay:** Each game is different due to the fact that at the beginning of each game, evidence pictures and their captions are drawn at random. This ensures the uniqueness of the games.

6.1.3 Monitoring

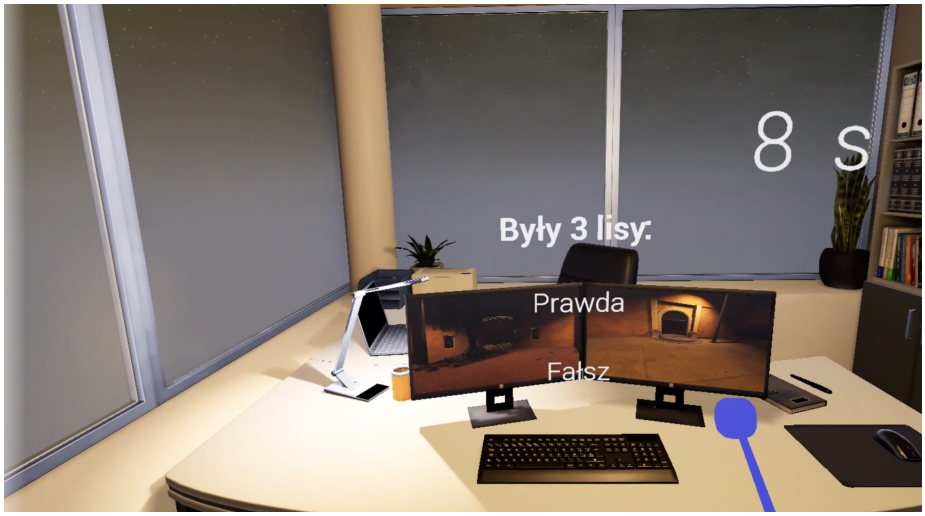

Figure 12: Monitoring game: the player answers the quiz

- **The main idea:** The player is in a room with monitors that show animals passing by. The player's task is to look at the monitors, memorize the events, and then answer true-false or one-choice questions about the events on the monitors. The questions are displayed in front of the player and the answers might be chosen with the use of a laser attached to the player's hands. An example of how the scene looks during gameplay is shown in Fig. 12.
- **Increase of difficulty:** As the difficulty level increases, the number of events (passing animals) on the monitors increases.
- **Counting player score:** The player receives one point for each correct answer, zero points for an incorrect answer. The maximum number of points available equals the number of questions in the game.
- **Variety of gameplay:** Variety in the gameplay is ensured by drawing the species of animals, their number and the path on which they move. Questions about events are also randomly generated.

6.1.4 Safe

Figure 13: Safe game: the player tries to complete the cog system

- **The main idea:** The player is in a room containing a safe with a three-dimensional cog system in which some elements (cogs) are missing. The player's task is to complete the pinion system within 30 seconds. The player can grab the cogs that are on the table in front of the player and put them inside the safe to complete the system. Additionally, there are confusing cogs on the table that do not fit into the system. An example of how the scene looks during gameplay is shown in Fig. 13.
- **Increase of difficulty:** As the difficulty level increases, so does the complexity of the system and the number of missing cogs in it.
- **Counting player score:** Points are awarded to the player for correctly completed pins, for incorrectly completed pins the player receives zero points.
- **Variety of gameplay:** Variety between gameplays is ensured by random generation of rack systems, as well as randomization of missing rack systems. Also, misleading cogs are drawn.

6.1.5 Testimonies

Figure 14: Testimonies game: the player recreates the order of testimonies

- **The main idea:** The player is in a room with witnesses of an event. The witnesses, in a random order, each say a sentence about the crime.When all the witnesses have said their lines, the player, using a laser pointer, must indicate the order of testimony within a limited time. An example of how the scene looks during gameplay is shown in Fig. 14.
- **Increase of difficulty:** As the difficulty level increases, the number of witnesses and their statements increases.
- **Counting player score:** Each correctly named witness is counted as 1 point. The score is displayed as points, but also as a percentage.
- **Variety of gameplay:** The games are different because with each new game, the characters' meshes, their positions and their utterances are drawn (they are drawn from the database of recordings), so the games are different even with the same number of characters in the room.

6.2 Visual-spatial functions

6.2.1 Safe

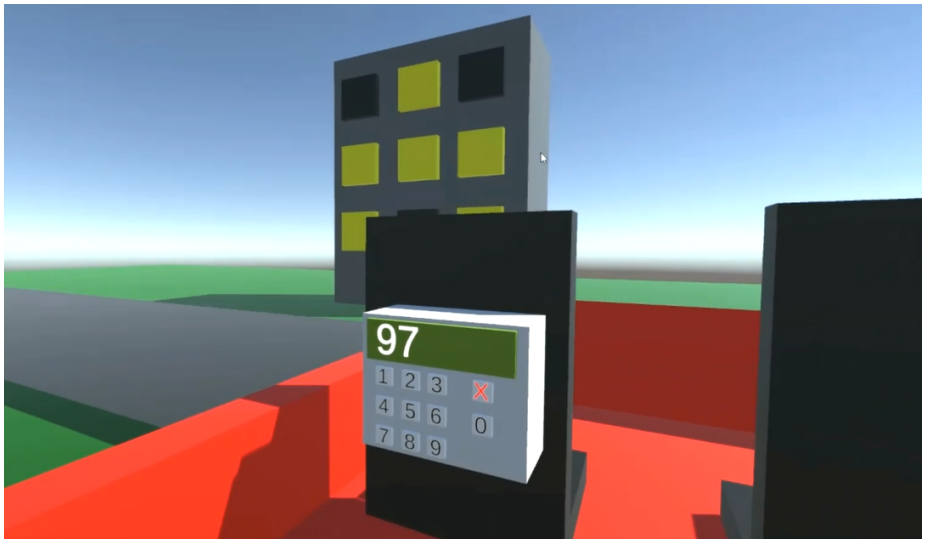

Figure 15: Safe game: player enters the safe code

- **The main idea:** Game „Safe" consists of a single round in which the player has to input the proper combination of digits in order to open the titular safe. During the whole gameplay the player is placed in a moving car which passes high-rise blocks. There is an amount of lighted windows in each of the blocks. The goal of the player is to count them and input a proper digit. Each block represents a single digit of the cipher. The concept of the game was designed to support development of perceptivity, quick thinking and working under time pressure. An example of a game is shown in Fig. 15.
- **Increase of difficulty:** The game can be run in one of the five difficulty levels. The level defines the car's speed and the amount of high-rise blocks placed on the map (which means the length of the code to be broken).
- **Counting player score:** The game is completed if the cipher was broken.
- **Variety of gameplay:** Every session the number of lighted windows of each block is randomized at the beginning, therefore each gameplay differs from others.

6.2.2 Chests

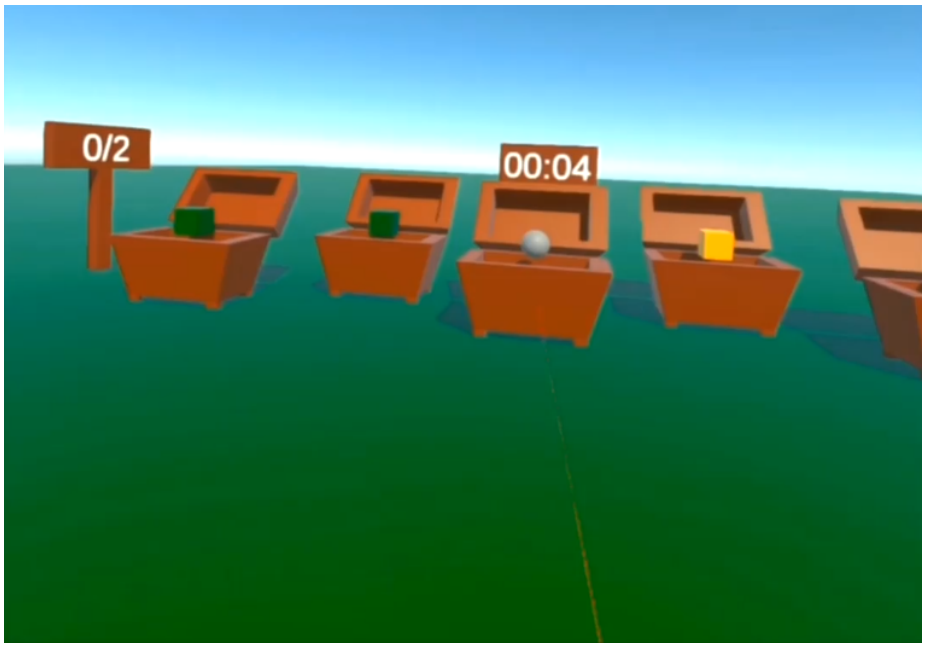

Figure 16: Chests game: player selecting changed chest content

- **The main idea:** Game „Chests", shown in Fig. 16, is divided into short rounds. In each of them there are chests which open and expose items hidden in them. Each chest contains only one item. Every round all items but one are the same as the previous round. The player's task is to point a chest with the fresh item. Game was designed to develop the player's memory and concentration.
- **Increase of difficulty:** The game can be run in one of the five difficulty levels. Each level defines the number of total chests and the differentiation of hidden items.
- **Counting player score:** The more chests a player points correctly, the more points he gets.
- **Variety of gameplay:** Every round the items in the chests are generated randomly.

6.2.3 Balloons

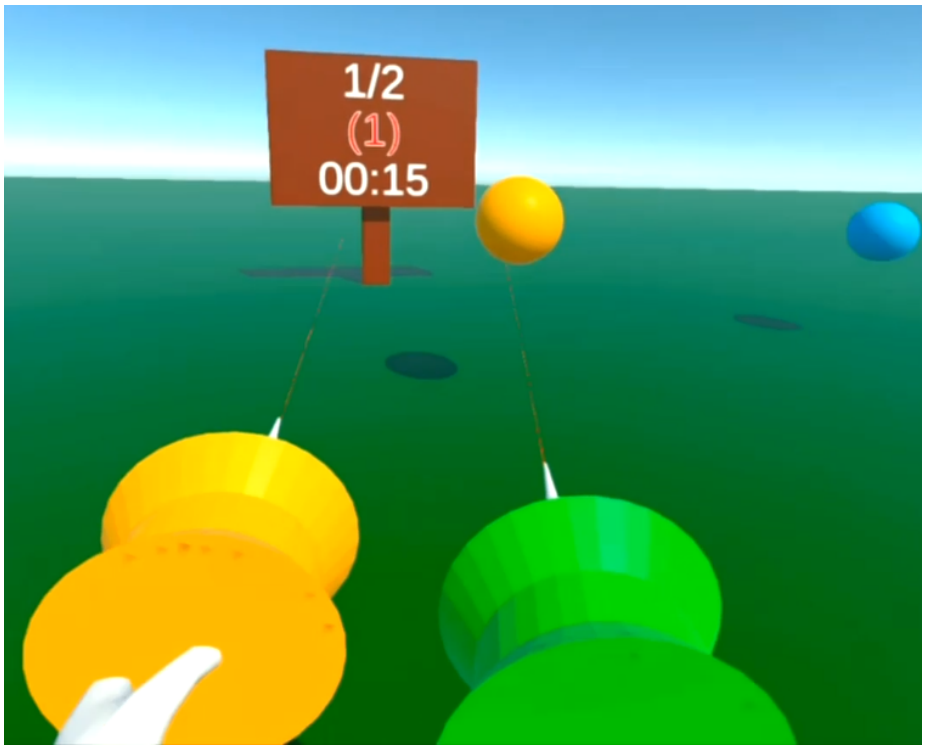

Figure 17: Balloons game: player tries to pop balloons

- **The main idea:** Game „Balloons" consists in popping floating balloons with the usage of two thumbtacks each held in a different hand. There are predefined colors assigned to both tucks and balloons. The goal is to pop only those balloons whose color matches the color of the thumbtack. The game bases on hand-eye coordination and also forces players to use their both arms to perform different moves. A scene from an game is shown in Fig. 17
- **Increase of difficulty:** In addition the game can be run in one of the five difficulty levels. Each level defines the speed of the balloons, the frequency of their spawning and the differentiation of balloons' color.
- **Counting player score:** Player gets points for good pops and get penalty points for the missed balloons and the ones popped incorrectly.
- **Variety of gameplay:** Each gameplay is different from the others for the tucks' colors are randomized at the beginning of the game and the balloons' colors are randomized during the session.

6.2.4 Target Shooting

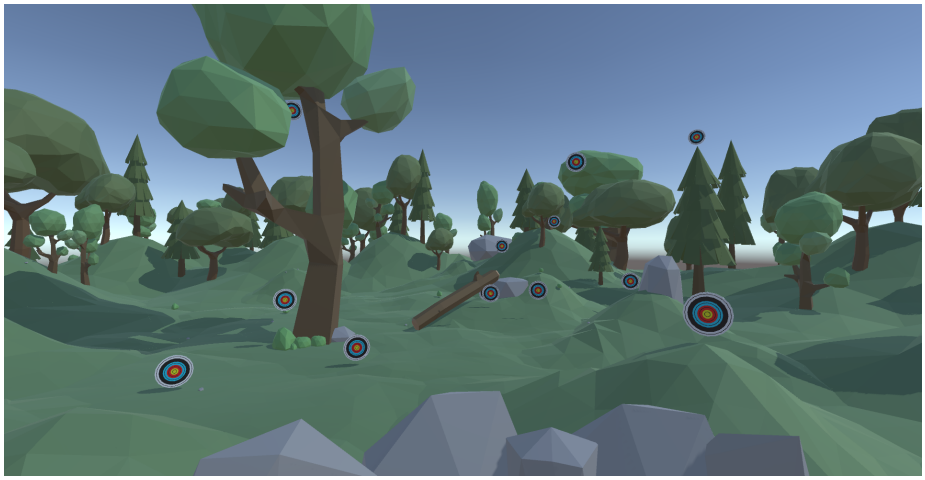

Figure 18: Target Shooting game: the appearance of the shooting range

- **The main idea:** Game "Target Shooting" is an FPS game in which you shoot stationary and moving targets shown in Fig. 18. The player is "locked" in place by rocks. Targets appear before the player in varied distance and position, some targets are moving. When the player hits the target, new targets spawns, so the overall amount of targets stays the same. The goal is to hit as many targets as possible.
- **Increase of difficulty:** The game can run in 5 different difficulties. the easiest difficulty spawns the most targets and none of them are moving. With the difficulty increase, the number of targets decrease and the speed of the moving targets increase. The speed of the moving target is a random number between two hard-coded values that depend on the difficulty level.
- **Counting player score:** With each target hit the player receives score points.
- **Variety of gameplay:** Each time the player starts a new game, the location of the targets is different due to it being randomized.

6.2.5 Shadow Matching

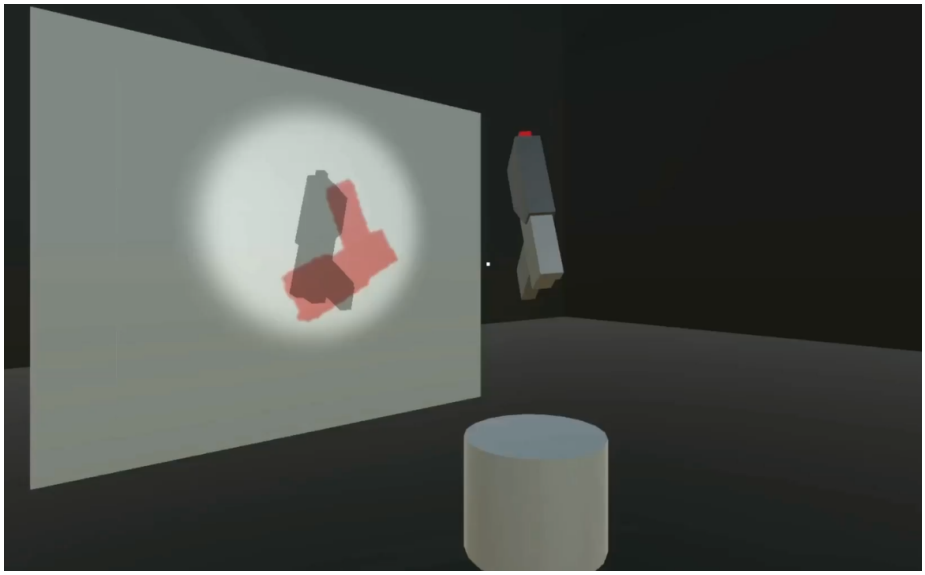

Figure 19: Shadow Matching game: player rotates object to cast correct shadow

- **The main idea:** Game "Shadow Matching" is a game in which the player matches the shadow of an object to the shadow outline on the wall by rotating it. An exemplary game scene is shown in Fig. 19. The player can grab an object and rotate it. The shadow an object casts is black, and the outline of the desired shadow is pink. Once the player matches the shadow both objects and the pink shadow outline rotate to a specific angle. Once the object and an outline finish rotating, the object starts accelerating in the direction of the wall on which the shadow was casted. When an object hits the wall, some particles explode from the wall. The object is deleted and a new one spawns. The object that spawns does not have to but may be the same object that was just matched.
- **Increase of difficulty:** With the increase of the difficulty new objects can spawn that are harder to match. Additionally the error margin between object rotation and the 'desired' rotation decreases.
- **Counting player score:** Whenever a player matches an object, he receives a score point.
- **Variety of gameplay:** Each time the player starts a new game a different object spawns at a different initial angle. Pink outline's angle is also different. Otherwise each round is the same.

6.2.6 Maze Plan

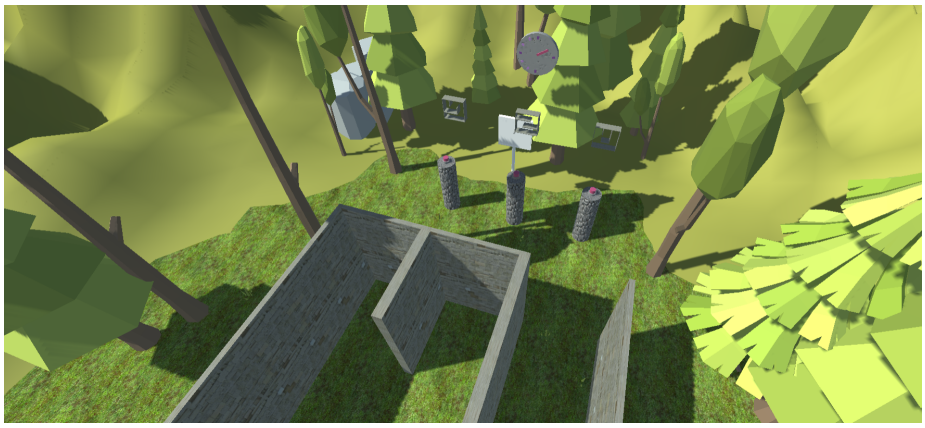

Figure 20: Maze Plan game: the appearance of Maze Plan game scene

- **The main idea:** The "Maze Plan" game consists in going through the maze and then selecting the correct plan of the maze. The player has to remember the presence of walls while passing, and then choose the correct maze projection. Each game is different because the maze is generated randomly. Additionally, the game can be played on various difficulty levels (there are 7 of them). The game is based on an exercise in spatial orientation and additionally includes calm bird sounds. The scene from the game is shown in Fig. 20.
- **Increase of difficulty:** Levels vary slightly with the size / difficulty of the maze and the rotation of the maze plans among others.
- **Counting player score:** The player gets a point for the correctly indicated answer.
- **Variety of gameplay:** Each game is different because the maze is generated randomly.

6.2.7 Figures Projection

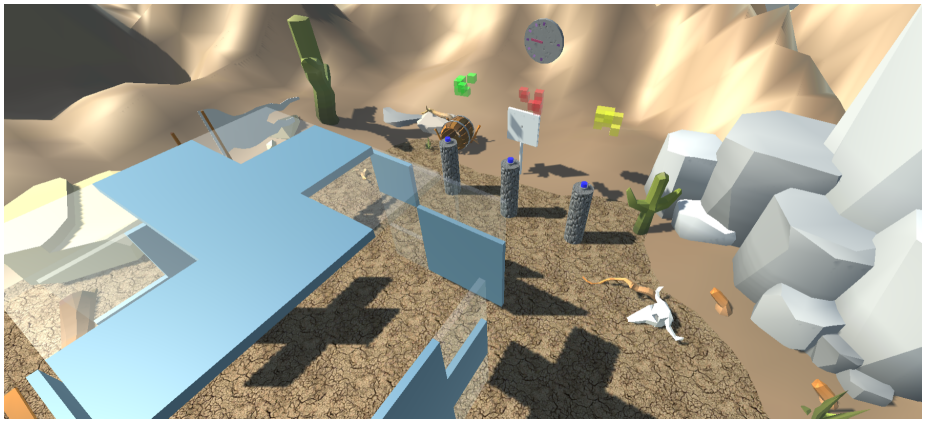

Figure 21: Figures Projection game: the appearance of Figures Projection game scene

- **The main idea:** The "Figures Projection" game consists in indicating the figure whose projection appeared in the space around the player. The view of an exemplary game scene is shown in Fig. 21. The throws appear in the form of walls in the center of which the player's original position is. Each game has a randomly generated figure and its complexity depends on the level of the game. The game was designed to train seeing figures in space. Additionally, it contains the calming sounds of the desert.
- **Increase of difficulty:** The complexity and size of the figure increases with successive levels. In addition, the gameplay at each of the eight levels differs with elements to choose from, such as rotation or transparency of figures.
- **Counting player score:** The player gets a point for the correctly indicated answer.
- **Variety of gameplay:** The figure is different in each game because it is generated randomly.

6.2.8 Terrain Grid

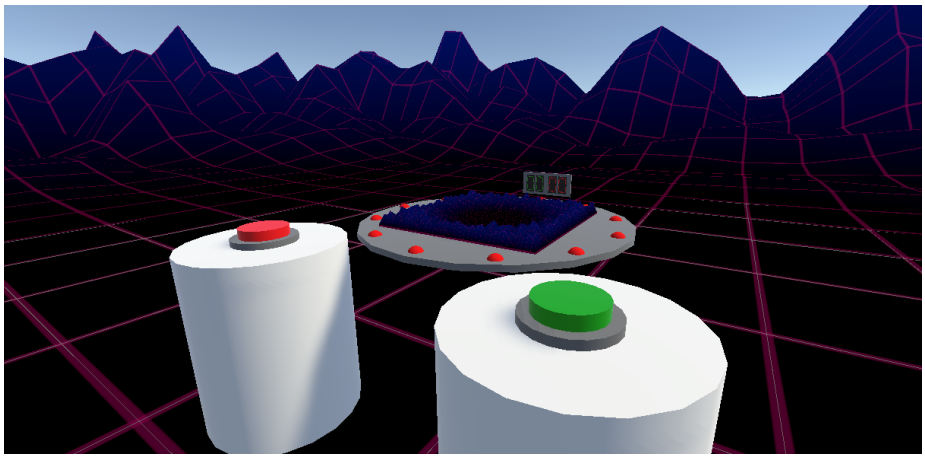

Figure 22: Terrain Grid game: the player determines if miniature corresponds to the surroundings

- **The main idea:** There is a miniature version of the terrain in front of the player. The player's goal is to indicate if this is exactly the same area he is in with the green and red buttons meaning Yes and No, respectively.An exemplary scene during the game is shown in Fig. 22.
- **Increase of difficulty:** The difficulty is modified by increasing the similarity of the incorrect answer terrain to the correct terrain.
- **Counting player score:** The player scores one point for a correct answer. However, punctuation can be calculated using modifiers depending on the terrain similarity, its movement or the rotation of the miniature.
- **Variety of gameplay:** The variety of gameplay is based on procedural terrain generation. In addition, over time, variety is introduced into the game in the form of moving terrain and a rotating miniature.

6.3 Visual-spatial memory

6.3.1 Maze Runner

Figure 23: Floor's map in Maze Runner game scene

- **The main idea:** The main goal of the game is to memorize a floor's map, which consists of normal rooms, rooms with keys and rooms with obstacles, and is presented in Fig. 23. A player has to collect all of the keys on the level and get to the last room, in order to unlock access to the next floor. A player has access to the floor's map only in the beginning room and should avoid obstacles at all times not to lose points.
- **Increase of difficulty:** With the increase of difficulty the number of rooms, obstacles and keys on the floor increases.
- **Counting player score:** A player earns points for every key they collect and every level they complete, but loses points for every obstacle encountered.
- **Variety of gameplay:** Depending on the difficulty level of the game, positions of keys and obstacles amongst a floor are randomized, which provides the possibility of creating a different game almost every time a player runs it.

6.3.2 Alchemist

Figure 24: Player remembers colors of potions on shelves

Figure 25: Potions have changed appearance to the same, player has to complete recipes shown on the scroll

- **The main idea:** Player has to remember where on the shelves are what potions - potions vary in color, shape and item inside the bottle, as is shown in Fig. 24. After 8 seconds, all potions change appearance to the same (e.g. original red and blue potions will now look the same, but would still be referred to as red and blue potions as in Fig. 25). Players' goal is to complete recipes by throwing into the cauldron the correct potions in specific order.
- **Increase of difficulty:** With difficulty increases the number of potions the player has to remember, number of potions' features and length of

recipe.

- **Counting player score:** Player receives points for throwing the correct potion into the cauldron. Bonus points are awarded if the whole recipe is done correctly. Higher difficulty levels also translate to higher score multiplier.
- **Variety of gameplay:** Many aspects of the game are randomized - potions' positions on the shelves, their features and recipes. This is enough features to create an unique game virtually every time.

6.3.3 Magic Duel

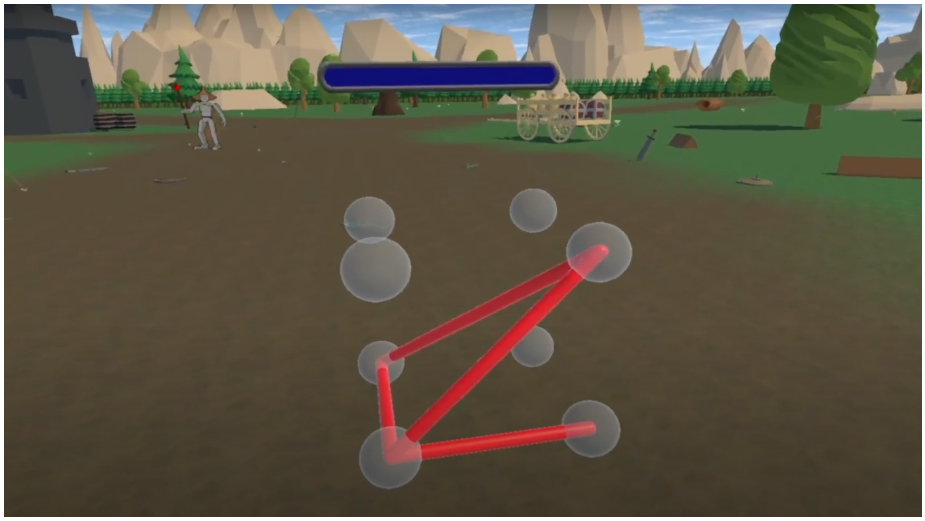

Figure 26: Player remembers magic sign template

- **The main idea:** Player has to remember the magic sign, shown on a grid of spheres as in Fig. 26. Then, he has to recreate this sign by creating the same connections between spheres with their hand as shown in Fig. 27. Magic sign disappears as soon as the player starts drawing.
- **Increase of difficulty:** Higher difficulty increases the length of the magic sign. Spheres grid is initially of 2x2 size, this size increases to 3x3 at certain difficulty level.
- **Counting player score:** Player receives points based on how close the recreated magic sign was to its original template. Bonus points are awarded if the magic sign was drawn perfectly. Higher difficulty levels also translate to higher score multiplier.
- **Variety of gameplay:** Even on the lowest difficulty level game can produce many different magic signs, which ensures that essentially every two games are going to be different.

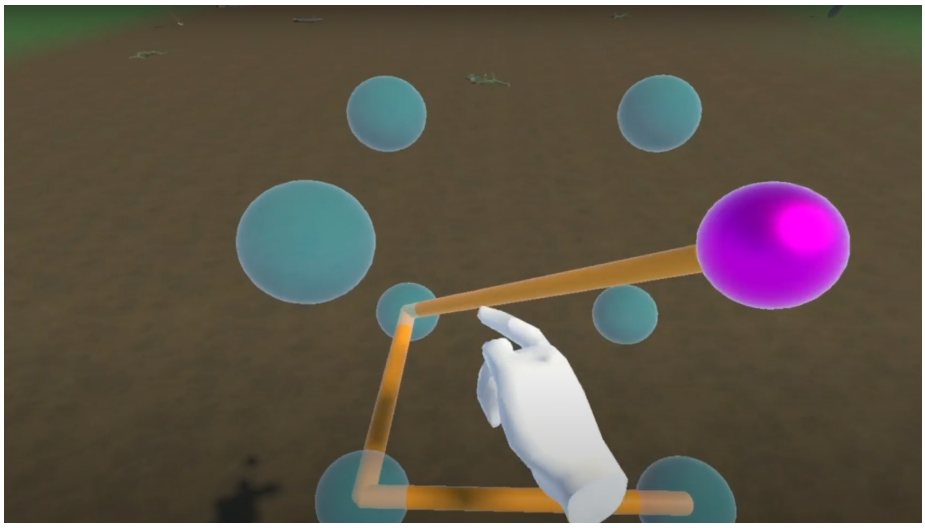

Figure 27: Player recreates the magic sign by connecting spheres with their hand

6.3.4 Candles

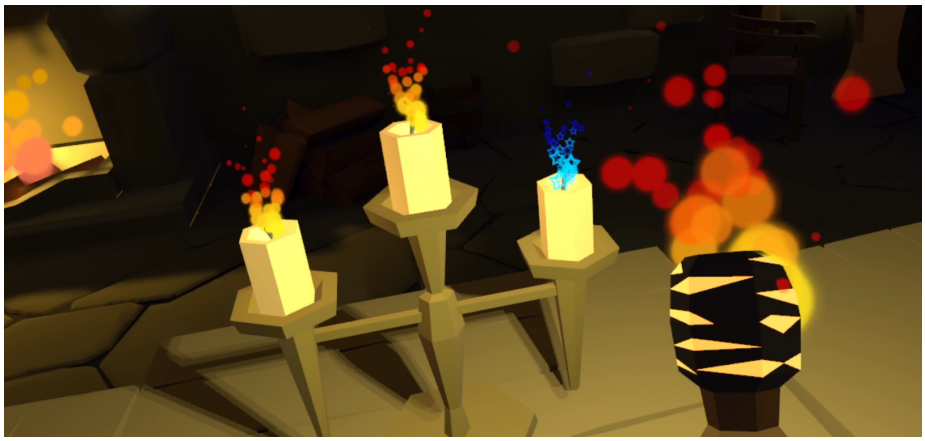

Figure 28: Candles game scene

- **The main idea:** Player is presented with candles that are either unlit or lit (in one of three colors), as shown in Fig. 28. After a couple of seconds the candles randomly change their state. Player needs to restore the original candle states by extinguishing flames with his hand and lighting candles with a torch, which can also change its color.
- **Increase of difficulty:** Higher difficulties increase the number of candles, which need to be remembered. On higher difficulties candles can take up to two more flame colors, for a total of three.
- **Counting player score:** Player receives points based on how many can-

dles are in the correct state (unlit or lit in correct color) at the end of the time limit.

- **Variety of gameplay:** The state of candles each time is randomized, so even on the lowest difficulty setting the player must face a new challenge every time. On different levels, the candles are in different positions on the table, and can be either single or three in one stand.

6.3.5 Perfect Shooter

Figure 29: Perfect Shooter game scene

- **The main idea:** Player must remember the position and color of the shields for a limited time. After it expires, the shields lose their color and the player can start shooting with the appropriate bolts as shown in Fig. 29.
- **Increase of difficulty:** The difficulty level increases by increasing the number of colors and the number of shields.
- **Counting player score:** The player scores points for each correctly hit target. For each miss, the score does not change, but hitting a target with a bolt of the wrong color subtracts half of the points awarded for the correct hit. For each difficulty level, the maximum points is 1300.
- **Variety of gameplay:** At each difficulty level, the position of individual points may change, and additionally, even for easier levels, where only 2 colors are used, they may be different each time.

6.3.6 What's New

Figure 30: What's New game scene

- **The main idea:** Player must remember the position of various items placed on shelves in a limited time. After it expires, new items appear and the player has to select items that were not there before as it can be seen in Fig. 30.
- **Increase of difficulty:** The difficulty level increases by increasing the number of items and shelves these items are placed on.
- **Counting player score:** The player scores a point for each correctly selected item. For each wrong selection, the player loses a point.
- **Variety of gameplay:** Both items and their positions are randomly chosen for each round.

6.3.7 Vanishing Things

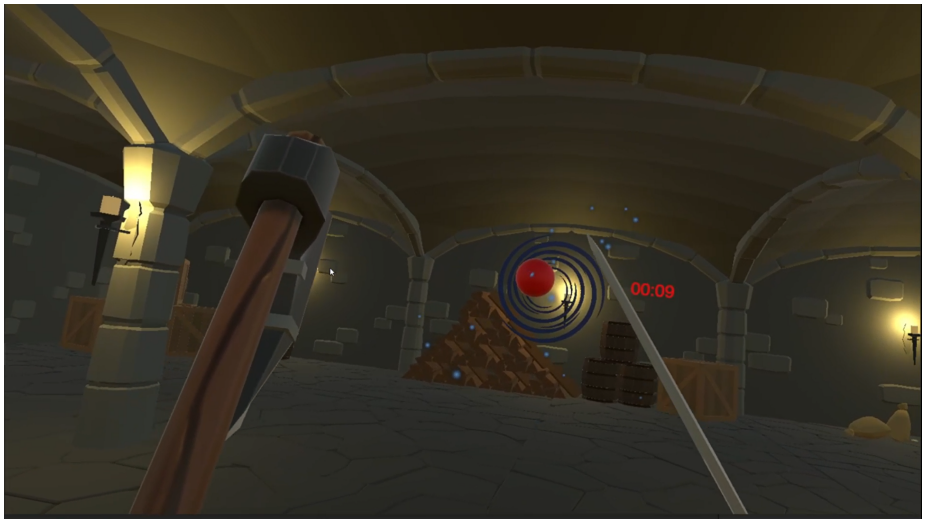

Figure 31: Vanishing Things game scene

- **The main idea:** Player must remember the trajectory and color of a flying object and destroy it with a sword or axe presented in Fig. 31. Objects are becoming invisible as they move towards a player.
- **Increase of difficulty:** The difficulty level increases by increasing the number of objects at the same time, increasing their velocity and changing their trajectory.
- **Counting player score:** The player scores a point for each correctly destroyed object and loses a point for every false destruction.
- **Variety of gameplay:** On each stage, start positions and types of objects are randomized.

6.4 Verbal memory

6.4.1 Tower Stacking

Figure 32: Tower Stacking game - putting a block on top of the tower

- **The main idea:** In front of the player, a tower made of several spatial figures is displayed. The player has to memorize the sequence and then recreate it using the blocks lying on the table, from which the tower was previously formed, by placing the blocks one on top of the other. An example of putting a block on top of another is shown in Fig. 32.
- **Increase of difficulty:** Before starting the game, the player can use the lever to select one of four difficulty levels: easy – a tower consisting of three blocks, medium – a tower consisting of five blocks, difficult – a tower consisting of six blocks, extreme – a tower consisting of seven blocks.
- **Counting player score:** The player receives feedback in the form of a message about a correctly or incorrectly stacked tower.
- **Variety of gameplay:** The game is available in four difficulty levels and the figures are randomly chosen from a pool of twenty space figures differing in shape or color.

6.4.2 Knob Sequences

Figure 33: Knob Sequences game - changing the position of the knob

- **The main idea:** Several knobs are displayed in front of the player, placed in random positions. The player must memorize the sequence presented. After learning the sequence, the player sees knobs in different positions in front of him, all set upwards. The user's task is to recreate the memorized sequence by turning the knobs. An example of changing the position of the knob is shown in Fig. 33.
- **Increase of difficulty:** Before starting the game, the player can use the lever to select one of four difficulty levels: easy – a sequence of three knobs, medium – a sequences of four knobs, difficult – a sequence of five knobs, extreme – a sequence of six knobs.
- **Counting player score:** The player receives feedback in the form of a message about a correctly or incorrectly arranged sequence.
- **Variety of gameplay:** The game is available in four difficulty levels and the knobs are drawn from a pool of eight knobs that vary in color. The position of the knob is also drawn.

6.4.3 Added item

Figure 34: Added Item game - choosing an additional item

- **The main idea:** Several starting items are displayed in front of the player. The player must memorize the items in front of them. After the player has familiarized themselves with the items, the initial items are presented on the table along with some additional items that were not previously on the stage. The player's task is to identify the new items. An example of picking an additional item is shown in Fig. 34.
- **Increase of difficulty:** Before starting the game, the player can use the lever to select one of four difficulty levels: easy – five starting items and one additional item, medium – six starting items and two additional items, difficult – seven starting items and two additional items, extreme – eight starting items and three additional items.
- **Counting player score:** The player receives feedback in the form of a message about correctly or incorrectly selected items.
- **Variety of gameplay:** The game is available in four difficulty levels and the items are drawn from a pool of eighteen different items.

7 Summary

Despite the fact that VR technology is relatively new, it is finding its way into many fields, including entertainment and the medical field. There are already solutions that combine the appeal of virtual reality gameplay with the rehabilitation of cognitive disorders in diseases such as stroke, Parkinson's, Alzheimer's, dementia or neurocognitive disorders. The effectiveness of these solutions has also been proven to be as good as, and sometimes even better than, traditional rehabilitation, due to the greater involvement and immersion of patients while

performing the exercises. The results obtained by the research group working on the present article indicate that rehabilitation based on VR games of cognitive disorders, namely executive function disorders, visual-spatial function disorders, verbal memory and visual-spatial memory disorders, in multiple sclerosis is possible and we hope that it may produce an effect similar or better than traditional therapy. However, in order to confirm this thesis, further research and experimentation would have to be carried out and studies would have to be conducted on real patients, which would require several months of collaboration with specialists who would supervise the progress of the patients, during rehabilitation using VR. All of the games developed by the team members and described in chapter 6 can be used as a supplement or substitute of cognitive impairment therapy for patients with multiple sclerosis, as these games are an interpretation of traditional rehabilitation exercises, transferred to three-dimensional space and with the addition of entertainment elements (training exercises are in the form of games).

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References

[1] Johanna Renny Octavia, Karin Coninx, Adaptive Personalized Training Games for Individual and Collaborative Rehabilitation of People with Multiple Sclerosis. *Biomed Res Int. 2014.*

[2] Siti Hazyanti Mohd Hashim, Marina Ismail, Haidzir Manaf, Fazah Akhtar Hanapiah, Development of Dual Cognitive Task Virtual Reality Game Addressing Stroke Rehabilitation. *3rd International Conference on Virtual and Augmented Reality Simulations, 2019.*

[3] J. A. Lozano-Quilis, H. Gil-Gómez, J. A. Gil-Gómez, S. Albiol-Pérez, G. Palacios, Habib M. Fardoum, Abdulfattah S. Mashat, Virtual reality system for multiple sclerosis rehabilitation using KINECT. *7th International Conference on Pervasive Computing Technologies for Healthcare, 2013.*

[4] Teresa Paulino, Ana Lúcia Faria, Sergi Bermúdez i Badia, Reh@City v2.0: a comprehensive virtual reality cognitive training system based on personalized and adaptive simulations of activities of daily living. *5th Experiment International Conference (exp.at'19), 2019.*

[5] Francisco Munoz-Montoya, M.-Carmen Juan, Magdalena Mendez-Lopez, Ramon Molla, Francisco Abad, Camino Fidalgo, SLAM-based augmented reality for the assessment of short-term spatial memory. A comparative study of visual versus tactile stimuli. *PLoS One. 2021.*

[6] Kevin Desai, Kanchan Bahirat, Sudhir Ramalingam, Balakrishnan Prabhakaran, Thiru Annaswamy, Una E. Makris, Augmented reality-based exergames for rehabilitation. *7th International Conference on Multimedia Systems, 2016.*

[7] Richard H. Y. So, K. P. Wong, S. L. Yuen, J. Tang, H. Yeung, J. Liu, Virtual reality gaming for rehabilitation: an evaluation study with physio- and occupational therapists. *10th International Conference on Virtual Reality Continuum and Its Applications in Industry, 2011.*

[8] Jack Shen-Kuen Chang, Georgina Yeboah, Alison Doucette, Paul Clifton, Michael Nitsche, Timothy Welsh, Ali Mazalek,Evaluating the effect of tangible virtual reality on spatial perspective taking ability. *5th Symposium on Spatial User Interaction, 2017.*

[9] Grigore C. Burdea, Colin Defais, Repetitive bimanual integrative therapy (RABIT) virtual rehabilitation system. *IEEE Virtual Reality (VR), 2013.*

[10] Grigore C. Burdea; Kevin Polistico, A review of integrative virtual reality games for rehabilitation. *E-Health and Bioengineering Conference (EHB), 2017.*

[11] M.N.A. van der Kuil, I.J.M. van der Ham, J.M.A. Visser-Meily, Game technology in cognitive rehabilitation of spatial navigation impairment. *International Conference on Virtual Rehabilitation (ICVR), 2017.*

[12] Martina Maier, Nuria Leiva Bañuelos, Belén Rubio Ballester, Esther Duarte, Paul F. M. J. Verschure, Conjunctive rehabilitation of multiple cognitive domains for chronic stroke patients in virtual reality. *International Conference on Rehabilitation Robotics (ICORR), 2017.*

[13] Monthon Intraraprasit, Phanuthon Phanpanya, Chompoonuch Jinjakam, Cognitive training using immersive Virtual Reality. *10th Biomedical Engineering International Conference (BMEiCON), 2017.*

[14] Giuseppe Caggianese, Andrea Chirico, Giuseppe De Pietro, Luigi Gallo, Antonio Giordano, Marco Predazzi, Pietro Neroni, Towards a Virtual Reality Cognitive Training System for Mild Cognitive Impairment and Alzheimer's Disease Patients. *32nd International Conference on Advanced Information Networking and Applications Workshops (WAINA), 2018.*

[15] Ho-Sang Moon, Sung-Wook Shin, Sung-Taek Chung, Eok Kim, K-CBS-based unilateral spatial neglect rehabilitation training contents utilizing virtual reality. *International Conference on Electronics, Information, and Communication (ICEIC), 2019.*

[16] Ana Lúcia Faria, Teresa Paulino, Sergi Bermúdez i Badia, Comparing adaptive cognitive training in virtual reality and paper-pencil in a sample of stroke patients. *International Conference on Virtual Rehabilitation (ICVR), 2019.*

[17] Christian I. Penaloza, Melanie Segado, Patricia Debergue, BMI-VR based Cognitive Training improves Attention Switching Processing Speed. *IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2020.*

[18] Jeffrey M Rogers, Jonathan Duckworth, Sandy Middleton, Bert Steenbergen, Peter H Wilson, Elements virtual rehabilitation improves motor, cognitive, and functional outcomes in adult stroke: evidence from a randomized controlled pilot study. *J Neuroeng Rehabil, 2019.*

[19] Jong-Hwan Park, Yung Liao, Du-Ri Kim, Seunghwan Song, Jun Ho Lim, Hyuntae Park, Yeanhwa Lee, Kyung Won Park, Feasibility and Tolerability of a Culture-Based Virtual Reality (VR) Training Program in Patients with Mild Cognitive Impairment: A Randomized Controlled Pilot Study. *Int J Environ Res Public Health, 2020.*

[20] Ana L. Faria, Mónica S. Cameirão, Joana F. Couras, Joana R. O. Aguiar, Gabriel M. Costa, Sergi Bermúdez i Badia, Combined Cognitive-Motor Rehabilitation in Virtual Reality Improves Motor Outcomes in Chronic Stroke – A Pilot Study. *Front Psychol, 2018.*

[21] Kristen M Triandafilou, Daria Tsoupikova, Alexander J Barry, Kelly N Thielbar, Nikolay Stoykov, Derek G Kamper, Development of a 3D, networked multi-user virtual reality environment for home therapy after stroke. *J Neuroeng Rehabil, 2018.*

[22] Carmen Nélida Waliño-Paniagua, Cristina Gómez-Calero, María Isabel Jiménez-Trujillo, Leticia Aguirre-Tejedor, Alberto Bermejo-Franco, Rosa María Ortiz-Gutiérrez, Roberto Cano-de-la-Cuerda, Effects of a Game-Based Virtual Reality Video Capture Training Program Plus Occupational

Therapy on Manual Dexterity in Patients with Multiple Sclerosis: A Randomized Controlled Trial. *J Healthc Eng, 2019*.

[23] Ying-Yi Liao, I-Hsuan Chen, Yi-Jia Lin, Yue Chen, Wei-Chun Hsu, Effects of Virtual Reality-Based Physical and Cognitive Training on Executive Function and Dual-Task Gait Performance in Older Adults With Mild Cognitive Impairment: A Randomized Control Trial. *Front Aging Neurosci, 2019*.

[24] Martina Maier, Belén Rubio Ballester, Nuria Leiva Bañuelos, Esther Duarte Oller, Paul F. M. J. Verschure, Adaptive conjunctive cognitive training (ACCT) in virtual reality for chronic stroke patients: a randomized controlled pilot trial. *J Neuroeng Rehabil, 2020*.

[25] José Varela-Aldás, Guillermo Palacios-Navarro, Rebecca Amariglio, Iván García-Magariño, Head-Mounted Display-Based Application for Cognitive Training. *Sensors (Basel), 2020*.