Game-based Training of Cognitive Functions: An Exploratory Study Involving Seniors in Switzerland

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Abstract: The aging population is resulting in a worldwide rising prevalence of individuals experiencing cognitive decline, whether it be normal age-related changes or pathological conditions. Game-based training in the form of serious games represents an alternative way to enhance cognitive functions among older people. We developed a set of games to train multiple cognitive functions of seniors, considering that their level of digital literacy can vary greatly. A participatory approach has been applied to the development process, involving a multidisciplinary research team and older people. Interviews, usability tests, and a workshop were run with ten seniors (70+) in Southern Switzerland to explore accessibility, usability, and preferences. This paper presents the development process and the games created. Six different games were designed to stimulate multiple cognitive functionalities (e.g., cognitive flexibility, attentiveness, and memory). The serious games run on a tablet. Following Laamarti's classification, we developed the games to be applied in well-being and health areas, requiring mainly mental activities through visual modalities, played through a touchscreen in a 2D digital environment. Participants appreciated the experience and the challenges provided by the games, understanding the broader aim (cognitive functions training) and the rules, and could complete the required tasks. Feedback was provided on graphical elements (icons and colours), as well as with suggestions for improvements. The tablet appeared to be functional and relatively easy to use, even for first timers. The promising results of this participatory study pave the way for the follow-up phase of the project, which will gather data on the usage of the application and its effectiveness with a greater number of subjects.

Keywords: Game-based Training, Cognitive Functions, Cognitive Decline, Serious Games, Older People

1. Introduction

The rapidly aging population is changing the demographic landscape of countries worldwide, challenging healthcare systems that struggle to fund care for older people (Humphreys, 2012). Data from the Swiss Federal Statistical Office (Ufficio federale di statistica, 2024) reflects a noteworthy increase in the mean age of the population over recent years. Southern Switzerland, in particular, has experienced a pronounced growth, and it now represents the Swiss region with the highest aging rate. As the population ages, cognitive decline emerges as a critical concern. While physiological aging processes contribute to cognitive decline, additional factors such as drug side effects, metabolic changes, and illness-induced delirium can exacerbate the issue. Conditions like depression, subjective cognitive impairment (SCI) or mild cognitive impairment (MCI), and dementia further highlight the complexity of cognitive health in aging populations (National Institute on Aging, 2024). While some of the causes, like depression and medication side effects, can be managed and the cognitive abilities restored, other conditions, such as SCI or MCI, represent possible targets for interventions to delay progression into dementia.

Cognitive intervention is generally intended to 'exercise the brain' in various ways as it is regarded as an effective non-pharmacologic strategy to mitigate risks in neurodegeneration. Computerized cognitive training (CCT) refers to cognitive training programs delivered by means of computers or mobile technology and is effective in attenuating cognitive decline in older adults with MCI or dementia (Hill et al., 2017). Serious games are a captivating and explored tool that shows promising results in addressing pathological and physiological cognitive

decline symptoms. Definitions of serious games vary, but they share a common thread: delivering a meaningful message that transcends mere entertainment, as they serve as a platform for training, teaching, learning, and much more (De Gloria et al., 2014; Michael & Chen, 2006; Rodríguez et al., 2021). Laamarti, Eid and El Saddik (2014), suggest five criteria to classify serious games: the area of application of the game (health, education, etc.); the type of activities (physical, mental, etc.); the delivery mode (visual, auditory, etc.); the human-computer interaction style (joysticks, eye gaze measurement, etc.); and finally, the environment in which the game is played (virtual reality, social presence, etc.). This classification emphasizes how versatile serious games can be, serving a variety of uses in a wide range of circumstances.

Over the past two decades, many researchers have delved into the topic of serious games by exploring their potential applications in addressing cognitive decline among older adults. Specifically, these games serve two primary objectives: the assessment and the training of cognitive functions. On the one hand, assessment games often integrate existing screening technologies to evaluate cognitive abilities. For instance, Nolin et al (2013) proposed a virtual reality game aimed at distinguishing between healthy and MCI participants based on prospective memory assessment. Similarly, another study examined the reliability of computerized touch-panel screening games for diagnosing Alzheimer's disease and MCI. Examples of such games include "beating devils", which simulates tasks similar to "whack-a-mole", focusing on working memory, and the traditional "flipping card" game, which assesses short-term memory skills (Fukui et al., 2015). On the other hand, training via serious games entails sustained engagement aimed at preserving or enhancing cognitive abilities. These interventions can be more effective than engaging in conventional exercises or receiving no intervention in the context of seniors with cognitive impairment (Abd-Alrazaq et al., 2022). Furthermore, cognitive training can be implemented through various games targeting distinct abilities. Memory, attention, and executive functions are among the most frequent capacities stimulated in this context; this trend is tightly related to the neurobiological underpinnings of the aging process, which primarily affect such functions (Peters, 2006). Memory deficit, for example, is one of the most observable and common symptoms among individuals with MCI or early dementia that disturbs the quality of life. Moreover, using a set of games can stimulate multiple cognitive abilities simultaneously. For instance, a study conducted by Simoes et al (2019), tested an older population with a group of serious games designed to maintain and/or enhance various functions such as memory, attention, language, and executive functions. These abilities are engaged through games like "Pairs", a memory game, "Puzzle", requiring attentional effort, or "Whack-a-mole", stimulating sustained attention and inhibition. Similarly, another study led by Ríos Rincón et al (2022) utilized games such as "Whack-a-mole", "Word Search", or "Mahjong Solitaire" to concurrently stimulate selective attention, short-term memory, and processing speed.

For the SIGMA project, we developed a set of serious games targeted to the local population to train multiple cognitive functions of older people. To develop the games, we followed some of the key guidelines of design of games for the seniors presented in Chilufya (2014). Research has shown that digital games can provide enjoyment and relaxation, help escape from reality during times of grief or loneliness, stimulate with the challenge of completing a game and achieving high scores, and enhance one's skills. Digital games offer an opportunity to remain connected with society, add purpose to their days, and engage in brain training. They can also provide the chance to teach others rather than being solely trained by the game and therefore enhance social connectedness and promote interaction (Nap et al., 2009). The novelty of our research is the use of such games not only for the training, but also for monitoring cognitive performances by healthcare professionals in the context of home care services. In this paper we focus on the development process and describe the final games.

2. Study Design

A participatory approach was applied to the games development process by involving a multidisciplinary research team (research nurse, engineers and software developers, a graphical designer), a neuropsychologist, seniors, and geriatric nurses. The study comprises four stages. Firstly, a literature review was undertaken followed by qualitative interviews conducted with both geriatric nurses and seniors to explore needs and preferences. Findings informed the development of six serious games for the cognitive training of seniors receiving home care. Games were included in the beSerious app supported by a platform that allows nurses to monitor changes. Usability tests and a workshop with seniors and geriatric nurses were conducted to gain feedback along the development process. Such approach facilitated the definition of the games' features. In the next phases of the project, the games and the platform will be implemented in clinical practice with home care users and nurses. Ethical clearance was gained by the Comitato etico cantonale Ticino.

3. Qualitative Feedback

3.1 Pre-development Phase

Eight interviews were conducted with older people (4) and the geriatric nurses (4) to explore seniors' relationship with technology, games and mobile games (played on a mobile device like a smartphone or tablet), but also their digital skills and gather insights on preferences and barriers that could inform the games features and the development process. Nurses were of help to investigate technical aspects that needed to be considered for patients dealing with potential cognitive impairment, including the use of bright colours, lights, and sounds. Bright lights and sounds can, in fact, overstimulate older people, especially if they play games late in the evening.

During the interviews we also let seniors play some games[1] on a tablet to gain a more direct and realistic "hands-on" feedback.

The smartphone is the most frequently used device, with all seniors interviewed having and regularly using one. One person regularly uses a PC and other two had a tablet. Smartphones are primarily employed to stay in contact with family and friends, but also to play games; while the tablet is used mostly to play games, do searches, and look for information on the internet. When it comes to gaming, tablets are thought to be the best option because they are easier to use than computers and have larger screens than smartphones. Moreover, evidence suggests that the use of smartphones and tablet can aid cognitive functions, especially executive functions and processing speed (Wilson et al., 2022). Seniors mostly liked the games related to cards and words, which they found particularly stimulating. Moreover, some of the games we showed them were considered too simple or boring from a graphical perspective and not enough challenging. Instead, the curiosity message that showed up at the end of each level in one of the games was well-received by seniors since it increased their interest and taught them something new. Scoring systems and playing against the computer received mixed feedback from the interviewees, as these are seen from some as a motivator to play with points fostering a healthy sense of competitiveness, while for others these represent a source of stress.

Nurses reported that the most important cognitive areas to evaluate are memory, attention, and language, as these provide a general view of a person's cognitive status. Attention is a fundamental element in cognitive assessment, as the sudden loss of this in patients with a cognitive decline indicates a potential worsening in the global cognition. Similarly, a decline in the language areas could hide a rapid deterioration of cognitive functions. The games were seen as an interesting tool for prevention and an additional resource for the nurses to monitor the patient's cognitive status. However, it could implicate additional workload, as the nurses would need to check the platform regularly to ensure effective monitoring. To encourage older people playing, nurses suggested that the games are engaging and that the patient see a benefit in using them. They were concerned that the patients could feel supervised and will stop playing, and that having the same level for all the users could be boring for some of them and too difficult for others. Some interesting and useful data to be collected from the game would be the frequency of playtime, the time they took to finish the level, how many errors have been made, the final score, and which games the users choose to play. They anticipated that if the user would suddenly stop playing, it could be used as an alert.

Findings from this initial phase allowed the research team to identify the games to be developed and some of the features to be included in or excluded from these games. Information gathered were discussed extensively with a neuropsychologist and the team of game developers. Six games were chosen based on the state of the art of serious games targeting older adults, seniors' preferences, and cognitive areas to be stimulated.

3.2 Test Phase

Usability tests and a workshop were used to collect feedback and insights from future target users to be incorporated in the development and refinement of the games.

[1] Games were downloaded from the App Store and were the following: Word of Wonder, Jigsaw Puzzle, Candy Crush Saga, June's Journey, Cooking Mama, and Tetris. Some people played more than one game.

3.2.1 Feedback Usability Test

Two seniors participated in a two-month usability test. They received a tablet with the games and could play freely. We were not interested in quantifying the number of hours the participants played the game. At the end of the test, in-depth feedback was collected. Seniors liked the stimuli provided by the games as they felt they had a higher purpose than simply entertaining, especially the one focusing on language skills. One reason to play the games was their ability to improve several cognitive domains. One participant perceived the set of games as a valuable tool for nurses to identify cognitive issues that might go unnoticed by the individuals themselves, allowing healthcare professionals to intervene on time. The other participant liked attention-stimulating games because they were perceived useful. They found some games difficult to play, but the more they played the easier they became. Overall, they felt satisfied after finishing a game.

3.2.2 Workshop

The 13th of March 2024, we organised a workshop with four seniors to receive feedback on the usability and accessibility of the complete set of six games (Figure 1). Participants are currently receiving some form of home care services provided by the ACD Mendrisiotto, a homecare and assistance association in Southern Switzerland. They varied in age and gender (from 73 to 87 years old, 50% women), health conditions, and in technological competencies. Three out of four were not used to play mobile games. For one participant it was the first interaction with a tablet. We presented the project, the set of games, and the purpose behind such games (cognitive functions training). Participants had the opportunity to play every game in autonomy or with the support of a team-member. We collected feedback, suggestions, questions, but also notes from observing the participants while playing. Participants were also asked to provide their preferences in relation to different graphical elements (e.g., icons and colours used in the app).

Overall, they appreciated the experience and the challenges provided by the games; they understood the broader aim and the rules of the games and could complete the tasks required. The tablet appeared to be functional and relatively easy to use, even for the first-time user. Participants liked to play in couples as they could challenge each other and socialise while playing. The feedback received was used to finally refine the games.

Figure 1: Usability and accessibility workshop with seniors

The project is attracting the attention of various local entities, ranging from services providing care to people affected by dementia, to local media. The Swiss television channel Radiotelevisione (RSI), for example, was present during the workshop and produced a television report on the project[2].

4. Game Design and Development

The beSerious application presents itself as a game where players can traverse Europe's capital cities by playing the games. The journey theme aims to motivate the players to discover more information about European capitals. In fact, by successfully completing three games out of six, the application shows a curiosity about the visited city, and the next country is unlocked.

[2] https://rsi.ch/s/2095283

When launching the application for the first time, the interface prompts a tutorial that explains how the game works, and how players are supposed to play. This was a specific request made by seniors during the workshop, as they expressed concern in relation to the game starting immediately without having any pop-up instruction. The tutorial also explains the functionality of the buttons on top of the interface: hints, difficulty settings, and a "back" button to return to the Europe map screen (home screen).

The application was developed in Unity and is built to gather data on its usage (date and time played, data about the game played, games performances), which are stored on the device and, when Wi-Fi connection is available, securely sent and stored on a university-protected server. Researchers are working on a front-end accessible from the Web which can be used by nurses and caregivers to monitor players' performances and changes in cognitive functions.

The visual identity for the beSerious app took in close consideration the target users. In particular, the team developed a symbol/icon for the app that includes: a dice to symbolize the game, a smile to express inclusiveness and welcome but also a graphic element of contrast with the concept of games that have a "serious" purpose. These two elements (see Figure 2) led to an icon illustrating a smiling and friendly dice, easily recognizable by end users. Two different fonts were selected for the logo: one with serifs ("be") and one without serifs ("serious") to create contrast, both in bold to increase visibility. Furthermore, the letter "U" has been transformed into a smile, to reinforce the idea of play and cheerfulness. A careful analysis was also carried out on the meaning of colors, together with an analysis on readability by seniors as well as people suffering from color blindness.

Figure 2: beSerious app icon and logo

4.1 Games Developed for the Training of Cognitive Functions

The six developed and implemented games are: "Find the word", "Remember a sequence", Jigsaw, Whack-a-mole, "Three towers", inspired by the Tower of London (Shallice, 1982), and Labyrinth. Above all, such games stimulate executive functions, which are crucial for day-to-day functioning, but typically decline with age. Games are also useful in stimulating attentional and mnemonic abilities (particularly visuospatial). Table 1 shows the cognitive functions involved in each game. Some of them are the main target, while others are stimulated to a lesser extent. Below is a more detailed description of each game.

Table 1: List of cognitive functions stimulated by the six games.

		Find the word	Remember a sequence	Jigsaw	Whack-a-mole	Three towers	Labyrinth
Executive functions	Logical reasoning	ü		üü		üü	üü
	Cognitive flexibility	üü		üü		ü	ü
	Shifting	üü				ü	
	Strategy	üü	üü	ü		üü	ü
	Visuospatial abilities		üü	üü			üü
	Planning		ü	ü		üü	üü
	Working memory	üü				üü	üü
Memory	Short-term memory		üü				

		Find the word	Remember a sequence	Jigsaw	Whack-a-mole	Three towers	Labyrinth
Attention	Sustained attention				üü		
	Selective attention	üü	üü		üü	üü	üü
	Divided attention	üü	üü				

üü - primary stimulated functions

ü- secondary stimulated functions

4.2 Find the Word

Find the word (Figure 3) is a game inspired by the world-famous "Wordle" game. Players are given six attempts to guess a five-letter word, with feedback given through the game interface in the form of coloured tiles indicating a) if the letter is included in the word (green); b) if the letter is included but in the wrong place (yellow), and c) if the letter is not included in the word (red). The game prompts a digital keyboard on the screen. The game has been designed to allow the player to ask for hints. Hints let players ask for the first letter of the word, to reveal one letter on the digital keyboard (highlighted in yellow) that is part of the word, or to insert a correct letter in the attempt. The hints were specifically asked for during the workshop in march, where one participant expressed concern regarding the frustration when looking for a word without finding the first letter.

This game stimulates cognitive flexibility, shifting skills, working memory, as well as attentional functions. It draws inspiration from Verbal Fluency test (Carlesimo et al., 1996) and Wisconsin Card Sorting Test (WCST) (Laiacona et al., 2000). Verbal fluency provides information about the extent of and access to the lexical semantic storehouse, and it is considered a sensitive tool for predicting specific pathologies (such as aphasia, AD or other neurodegenerative diseases).

In the background, the game keeps track of the number and letters of attempts a player makes to find the word, the time taken, and the number and type of hints the player asks.

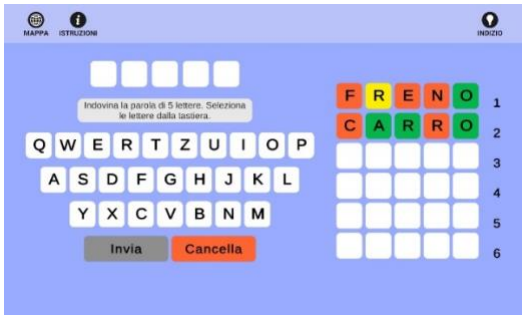

Figure 3: "Find the word" game

4.3 Remember a Sequence

In this game, the player is prompted with five cards. Each card gets coloured following a random sequence (Figure 4). The player's task is to remember and reproduce such a sequence by tapping the cards in the correct order. This game has no hint functionality implemented.

It stimulates visuospatial abilities, but also strategy and short-term memory. The theoretical reference is the Corsi Block Tapping Task (Monaco et al., 2013), which measures the amount of visual information (span) that can be retained in memory.

The game keeps track of the number of attempts a player makes to win it and the total time taken to finish. A wrong attempt results in a prompt suggesting trying again, showing on the background the cards that were chosen in the correct order (green border) and the ones chosen wrongly (red border). The sequence is shown again, giving players six tries in total. For cognitive function analysis, we will keep track of the time taken to perform a successful attempt.

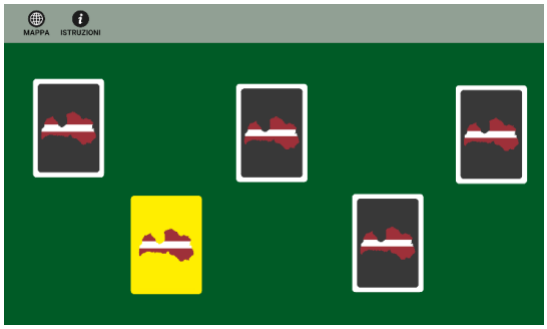

Figure 4: "Remember a sequence" game

4.4 Jigsaw

Players can choose between a puzzle with 16, 36, or 64 pieces. The system picks a random image from a collection of predefined images and generates a random puzzle with the given pieces.

Players should build the image in the empty play area. They can view or remove the backdrop image using a button on the top-right of the screen (this is the only hint present in the game). Players can travel between the pieces using a horizontal-scrolling bar on the bottom and they can drag-and-drop them to the play area. Adjacent pieces have a snap feature that connects and stays together when moved (Figure 5).

The game stimulates executive skills such as cognitive flexibility, logical reasoning, and visuospatial abilities. The difficulty settings chosen and the time to complete the jigsaw are data stored from the game.

Figure 5: "Jigsaw" game

4.5 Whack-a-mole

This game requires the player to tap as fast as possible on moles appearing from underground (Figure 6). There is a time limit of 60 seconds, and players must correctly tap at least 24 moles to pass the game.

Whack-a-mole is a simple game, yet it stimulates attentional skills, especially simple reaction time, i.e., alertness, or, better defined as the ability to act quickly and appropriately to concrete stimuli/environmental demands.

The game keeps track of the number of moles successfully tapped by the player, as well as the coordinates of the taps and the time of the tap, to compute delays in reaction times. Such data could be used in a future version to establish a scoring system and an adjustable difficulty setting that may affect mole speed based on player performance in previous games.

Figure 6: "Whack-a-mole" game

4.6 Three Towers

Three Towers is a Tower of London-themed game (Shallice, 1982). Players start with a three-pegged infrastructure with three coloured discs in a 3D scene. Leftmost peg can hold all three discs, middle peg two, and rightmost one. Players are given a final discs' disposition on the top-right screen and a restricted amount of moves on the top-left screen. The goal is to get from the beginning disposition to the final one. Figure 7 shows the game, composed with three levels to be completed, each with three tries. Players use fingers to drag-and-drop discs between pegs. Only the top disc in a pile can be moved to another peg.

The game primarily stimulates planning, strategy, working memory and logical reasoning, as well as attentional functions. The application keeps track of the time taken to complete each level and the number of attempts. There are no hints.

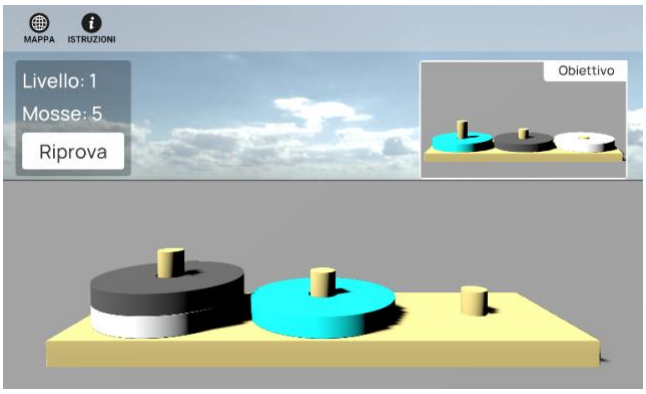

Figure 7: "Three towers" game

4.7 Labyrinth

Similarly to the Jigsaw game, players can choose from three difficulty levels based on labyrinth size. A new game is guaranteed by procedurally generating the labyrinth. To navigate the car from the starting position to the exit, players are given four arrows (these commands can be moved left or right of the screen with a button) (Figure 8).

If stuck, players can reset the labyrinth and start over with an interface button. The interface lets players create a new labyrinth of the same complexity or change levels if the game is too easy or hard.

The game stimulates visuospatial abilities, planning, and logical reasoning, but also working memory and selective attention. In the background, the application keeps track of the difficulty level chosen and the time taken to complete the track.

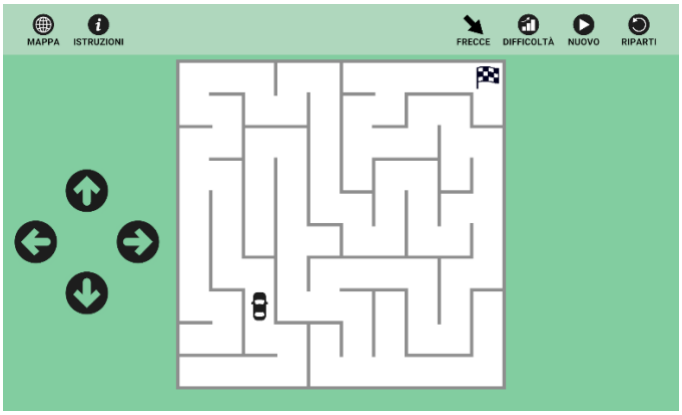

Figure 8: "Labyrinth" game

5. Conclusion

In this paper, we discussed the game design process and final output of beSerious, an application that provides serious games for cognitive training and monitoring of seniors using home care services in Southern Switzerland. Game-based training is used to improve cognitive functioning in older adults. We explored the local environment and stakeholders' demands, designed the games, tested the usability by potential users, and refined the games over a year and a half, from January 2023 to May 2024. Beginning in June 2024, the application will move into the data collection stage.

The promising findings show the importance of involving future target users in game development to explore technology and implementation issues, despite the small number of test users from the same social context and geographical area. The research team anticipated technological and practical issues with this inclusive strategy. Including user feedback and insights early in the development process allowed game designers and software developers to match game-based training products with user preferences and needs to improve uptake and engagement.

In the following phase, 15 to 20 people with none to mild cognitive impairment will play the games for 12 weeks. In a follow-up paper, results will be analysed and presented to show frequency of usage, games played more often, and game performance consistency over time, since long-term home training remains difficult.

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