Mosaic of Memory: a serious game to improve spatial and autobiographical memory in Alzheimer's patients*

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Abstract

Alzheimer's disease (AD) involves significant cognitive impairments that impact patients' quality of life. This paper proposes a novel computerized cognitive training (CCT) approach through both a web and mobile application called "Mosaic of Memories (MoM)" that aims to slow the deterioration of spatial and autobiographical memory in AD patients. MoM uses a serious game framework similar to the traditional card memory game, promoting spatial memory by requiring users to match pairs of cards on a virtual grid. Importantly, MoM integrates personalized and multisensory content, presenting images, names, and audio of meaningful individuals to stimulate autobiographical memory. The application also adapts difficulty levels based on user performance and incorporates a facial microexpression monitoring system to assess frustration levels during the game. MoM thus emerges as a dynamic cognitive training tool designed to stimulate spatial and autobiographical memory in AD patients, adapting to the user's profile and characteristics.

Keywords

Memory, serious game, Alzheimer's disease (AD), Artificial Intelligence (AI), Computerized Cognitive Training (CCT), spatial memory, autobiographical memory.

1. Introduction

Alzheimer's disease (AD) is the most common form of dementia and is a major cause of disability with a significant impact on the health of individuals and society.
Although the clinical presentation may vary in mild or early cases, AD tends to mainly affect the cognitive domains of episodic memory (EM), semantic memory (SM), and spatial abilities (SA)[1].
In addition to memory and visuospatial deficits, patients with AD manifest a variety of symptoms related to the cognitive and affective spheres (such as difficulty solving problems and feelings of sadness and lack of motivation) that significantly affect the patient's daily life [2] [3] [4].
Within the complex symptomatological picture presented by AD patients, memory deficits

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indeed represent one of the most debilitating aspects. In the following paper, we will focus on (i) spatial memory deficits and (ii) autobiographical memory deficits to propose a web and mobile application that serves as a compensatory exercise to slow down the deterioration of these two types of memory.

- **(i) Spatial memory**

  Spatial memory is a brain function responsible for recognizing, encoding, storing, and retrieving spatial information about the organization of objects or specific pathways [5]. Several studies [6] [7] have established the link between the hippocampus and memory for object location in space. However, hippocampal dysfunction, which is evident in patients with Alzheimer's disease and Mild Cognitive Impairment (MCI) [8] [9], leads to impairment in the ability to remember the spatial arrangement of objects.
  In addition, the hippocampus is also involved in processing viewpoint-independent spatial representations when comparing visual scenes [10][11] [12]. This element explains its role in understanding the spatial arrangement of a scene independently of the observer's perspective.

- **(ii) Autobiographical memory**

  Autobiographical memory constitutes a complex cognitive system that facilitates the retrieval of prior information, events, and personal experiences [13]. This system conceptually, chronologically, and thematically organizes autobiographical memories by operating on multiple levels of abstraction ranging from vivid sensory, perceptual, emotional, and conceptual details of specific moments to more general summaries of life periods [14] [15] [16].
  Such organization allows personal memories to be recalled and combined in various ways and for multiple purposes [17]. This type of memory is crucial for maintaining personal identity over time and consists of two main elements: personal episodic memory and personal semantic memory [18] [19] [20]. Personal episodic memory concerns the recollection of specific events in one's life with contextual details such as place, time, and people involved. In contrast, personal semantic memory includes personal information not directly related to events.
  Alzheimer's disease profoundly impairs both components of autobiographical memory [21] [20]. This leads to significant difficulties in recalling specific life events and general personal information. The resulting disorientation and loss of identity [22] deeply affect patients' sense of self and personal continuity.
  Currently, pharmacological treatments used to counteract early cognitive impairment in patients with AD are limited [23]. Given these limitations, there has been a surge of interest in compensatory cognitive interventions, such as Cognitive Training (CT), over recent decades. CT, which involves guided practice of tasks reflecting specific cognitive functions [24], holds promise in slowing cognitive decline associated with aging and disease. Its benefits can be observed even in the long term [25]. However, it is crucial that the training targets the main domains impacted by Alzheimer's disease, including

episodic memory, semantic memory, and visuospatial skills [26].
Computerized cognitive training (CCT) offers numerous advantages regarding accessibility and personalization. Indeed, it has been shown that CCT can improve episodic memory function and visuospatial skills in individuals with mild cognitive impairment [23]. However, training protocols must be optimized to maximize the transfer of benefits to daily activities [27].

In light of the evidence in the literature, in the following paper, we propose a CCT that consists of a web and mobile application based on a serious game called "Mosaic of Memories (MoM)." The goal is to train spatial and autobiographical memory in patients with Alzheimer's disease to slow the progressive degeneration of these two types of memory. Inspired by the traditional card memory game, the game requires patients to match pairs of cards placed on a virtual grid. To achieve a correct pairing, the patient must strive to remember the position of the cards on the grid, thereby exercising spatial memory. One of the main features of MoM is the use of personalized content in the form of cards, which contain images of people significant to the user matched with their respective names. This unique approach fosters emotional engagement during gameplay and effectively serves as an effective tool for exercising the patient's semantic autobiographical memory.
MoM stands out for its adaptability, offering training for both spatial and autobiographical memory. The application is designed to be highly customizable and user-centered, adjusting the game's difficulty level in real time based on the patient's performance. This is measured by the time taken to complete the game and the number of mistakes made, ensuring a tailored experience for each user.
MoM is designed with user comfort in mind. It features a support function that the user can activate after making three consecutive mistakes during the game session. This feature provides a visual hint through a pair of illuminated matching cards. This feature ensures patients can continue the game without frustration, even if they make mistakes. MoM is not just a game, it's a CCT tool. After each correct pairing (two matching cards), the user is shown a window containing information about the card (face and name).
This association stimulates semantic autobiographical memory due to the connection between image and name. MoM understands the importance of personal connections. That's why, at any time during the game, the user has the option of accessing the 'cherished individuals' function. This function allows the patient to view the card of all cherished individuals, containing their image, their name, and a short descriptive audio recorded directly from the cherished individuals. In this way, the user receives multi-sensory stimulation, integrating visual and auditory stimuli to make autobiographical memory stimulation more effective.
An additional innovative aspect of MoM is integrating a facial microexpression monitoring system that detects frustration, which can negatively affect the gaming experience. This data is recorded along with the gaming data in the "admin" panel of the user's profile and made available to the therapist and the patient's family to enable continuous monitoring of their emotional state and gaming performance trends over time. Each user account will have two profiles: one accessible to the patient to play and one accessible only to family members and therapists.

2. Related Works

The demographic crisis in Western countries has led to an increase in the elderly population and an increase in people with Alzheimer's disease, which is the most prevalent form of dementia [28]. People with dementia may experience difficulties such as memory loss, confusion, and behavioral disturbances that typically impair their ability to perform daily activities [29].
In an attempt to improve the quality of life of AD patients, numerous interventions based on nonpharmacological therapies have been proposed in recent decades [30][31]. Specifically, rehabilitation has become a recommended practice to improve patients' autonomy and interaction, delay cognitive and functional decline, and promote well-being [32].
The rehabilitation approach traditionally includes mobility and balance rehabilitation interventions, strategies to prevent falls, intensive physical exercises, cognitive stimulation, and psychological and occupational therapies [33]. However, the increasing prevalence of dementia has highlighted the need for more effective treatments, thus leading to a growing interest in new rehabilitation methodologies, such as serious games [34] [35].
In recent years, the video game industry has constituted the fastest-growing commercial sector among all entertainment media worldwide, and the evolution of these technologies has paved the way for the emergence and development of serious games. These digital games, unlike traditional games, have multiple purposes beyond entertainment, such as educational purposes [36], enhancement of users' abilities [37], and, in recent years, even training of cognitive functions for the elderly population [38]. The research community is not just interested but deeply invested in exploring solutions for game-based cognitive assistance [39] [40]. This strong interest underscores the relevance and urgency of this topic in our field. One example is the work of Nacke and colleagues [38], who examined the impact of digital games on handheld consoles, such as the Nintendo DS, on the elderly population. The research revealed that although elderly gamers were more proficient and accurate in solving game tasks using the traditional pen-and-paper method than the Nintendo DS system, the digital game experience for the elderly elicited a more incredible feeling of fun and engagement. This phenomenon can be explained through the concept of flow, representing a mental state of complete concentration and satisfaction in the play activity [41].
According to flow theory, to achieve optimal engagement, a game must have four essential elements: clear objectives, constant feedback, the ability to focus on activities, and the ability to complete activities. In addition, studies suggest that older people prefer games that elicit positive emotions and feelings of tension rather than excitement and extreme challenges [42]. Therefore, digital games need to adjust their difficulty and offer positive rewards to ensure a rewarding gaming experience for elderly players, thereby also improving their learning process [43].
Understanding the responses of the elderly during digital gaming activities has enabled the use of video games as less expensive and more accessible assistive tools. This is made possible by the fact that the mechanisms of serious games rely on specific cognitive, social, and behavioral skills that can be improved by increasing the time of play and the difficulty of challenges [44] [45]. These skills include motor skills, perception-attention, working memory management, content memory, reasoning, planning, problem-solving, and social interaction skills [46].
Several papers in the literature have examined the use of serious games for subjects with

cognitive deficits related to MCI, considered a possible precursor to Alzheimer's, and patients with AD.

One example is the 2020 work of Thapa and colleagues[47], in which the authors proposed a virtual reality (VR)-based cognitive training program for subjects with MCI. This program involved participants performing interactive activities via VR devices, such as a visor and two wireless controllers. The activities included games to exercise attention, memory, and processing speed. For example, participants could prepare juices following virtual recipes, shoot birds in a virtual beach environment, remember sequences of fireworks numbers, and organize objects in a virtual house. Each training session lasted 100 minutes thrice a week for eight weeks. Each session also included eye stretching exercises and massages to promote relaxation and reduce visual fatigue.

The results of the study showed that the group subjected to the virtual reality-based cognitive training intervention experienced a significant improvement in executive function and resting brain function compared with the control group subjected to a health care educational program.

Another example is the 2022 study by Liu and colleagues [48], in which patients with MCI underwent a Tai Chi training program based on serious games. The program included exercises that included typical Tai Chi movements, such as body weight shifting, limb movements, and coordination between movements and breathing. While performing the exercises, participants received real-time feedback on the screen, indicating their movements' accuracy. The work results showed significant improvement in global cognitive function, executive function, attention, and walking in MCI patients.

Several works in the literature have shown that serious games can be used not only as rehabilitation tools but also as diagnostic tools for patients with AD. One example is Sea Hero Quest [49], a game based on spatial navigation that challenges players to explore aquatic mazes to achieve specific goals. The game can be used as an early diagnostic tool, as it assesses users' navigation ability, a deficient skill in patients with AD [49]. It has been found that people with the apoE4 gene, which is considered a risk factor for the development of dementia in later life, show lower performance in spatial navigation tasks [50]. Therefore, using less efficient routes to achieve Sea Hero Quest goals may indicate cognitive difficulties.

Although several studies have been conducted in the literature on the use of serious games for people with AD, to date, there are still multiple vital limitations, as proposed interventions often need to take into account the specific sensory and interaction needs of individuals with AD. For example, many developed applications do not support cognitive error recognition during play and cannot dynamically adapt to the user's cognitive ability and profile [42] [51].

Similarly, the proposed interaction modes need to take full advantage of current technologies' naturalness and multimodal capabilities. In addition, the aesthetic design, including the use of colors, edges, and perspectives, is not optimized for people with cognitive impairments. Moreover, serious games aimed at Alzheimer's patients should consider all four cognitive spheres: memory, planning ability, initiative, and perseverance [52].

3. Methodology

The serious game "MoM" is designed to provide a therapeutic experience for Alzheimer's patients, using memory game as the basis. This game aims to stimulate autobiographical and spatial memory deficits in AD patients. The methodology of the game is illustrated in figure 1 and the guidelines used for the design are described below:

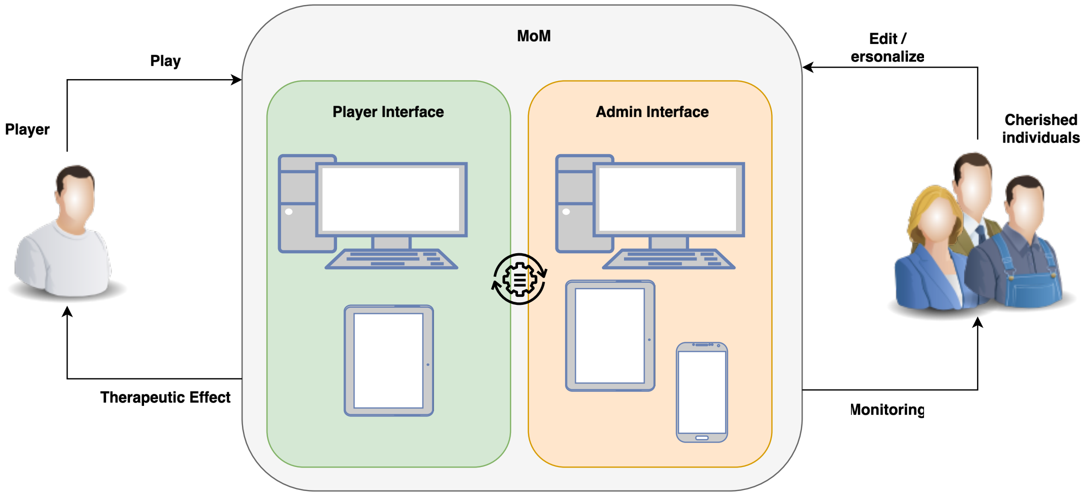

Figure 1: Illustration depicting the methodology of the MoM game, divided into two parts. On one side, the Alzheimer's patient interacts with the game interface, while on the other side, their cherished individuals the administrative interface.

3.1. Guidelines for MoM design

In section 2 of our paper, we discussed the limitations found in the literature regarding the design and development of applications targeting AD patients. In light of these shortcomings, during the design of MoM, we aimed to tailor the design and operation of the application to the characteristics of AD patients to improve the gaming experience and its effectiveness.

- **Autobiographical memory**
  One of the main goals of MoM is to slow the decline of autobiographical memory. Studies in the literature have shown that multimodal sensory stimuli positively influence the retrieval of personal memories and, in particular, that visual and auditory information play a central role in retrieving autobiographical memory [53]. For this reason, the application adopts a multimodal approach that uses multisensory stimulation, combining visual and auditory information to enhance information processing and memory retrieval. In fact, during the game session, the user receives visual stimuli (given by cards) and auditory stimuli (given by recordings of patients' cherished individuals).
- **Colors of the user interface**
  The initial selection of colors for the cards in the game grid and the background was made after a thorough review of the literature, which highlighted the interaction between color

and memory processes. Indeed, color can influence both encoding and retrieval of stimuli, and specifically, older adults benefit from using color to improve memory performance [54]. In the MoM design, we opted for green for the background of the cards and the names of the cherished individuals displayed after each correct pairing. Studies support this choice, indicating a better ability to remember green-colored stimuli, especially in older adults, than other colors, such as red or blue [54].

- **Dynamism of the game system**
  Two of the limitations found in the literature on "serious games" concern the lack of dynamic adaptation to the user's cognitive profile and the lack of support in case of errors [42] [51]. Our MoM game model offers different difficulty levels (easy, medium, expert) to overcome these limitations. The difficulty of the game can automatically adapt to the user's performance by selecting the auto mode, or be manually selected by the patient's cherished individual in the admin area. In addition, in both the auto and manual modes, visual feedback indicates the correct answer after three consecutive errors made by the user, allowing the user to continue the game while avoiding frustration.

3.2. Player Interface

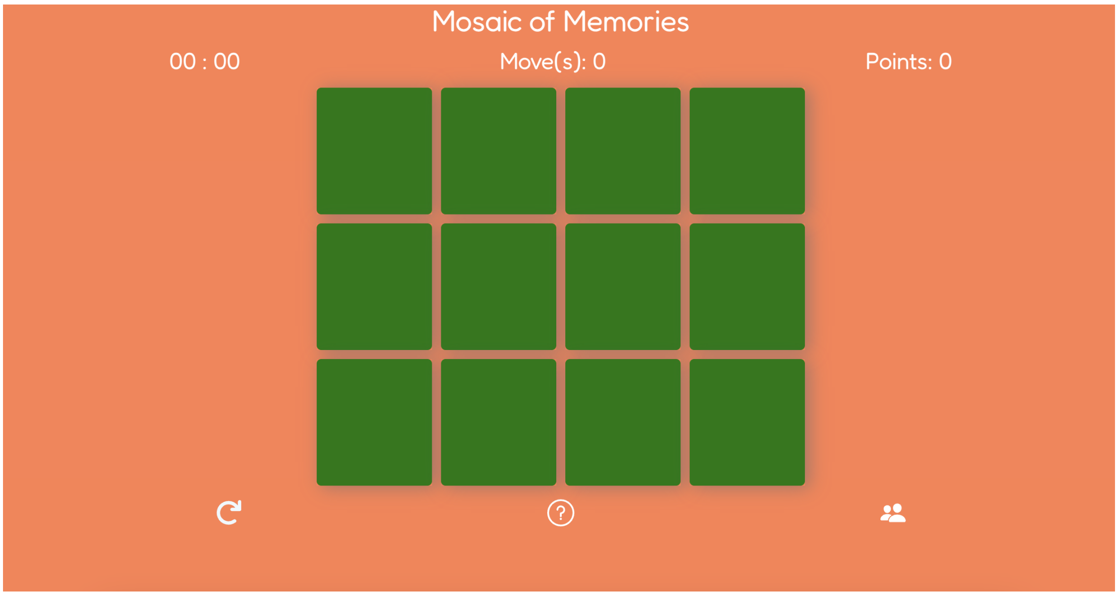

Figure 2: The initial game screen presents game metrics: time elapsed, move count, and correct pairings (points). Below are buttons for initiating a new game, accessing help, and view with cherished individuals.

The patient will have access to an initial interface in the easy mode with 12 boxes arranged in a 4x3 grid. Each box contains the face of a relative or cherished individual of the patient. The player can interact not only with the game tiles but also with three main buttons: "New Game", "Help" and "Cherished individuals" as shown in figure 2.

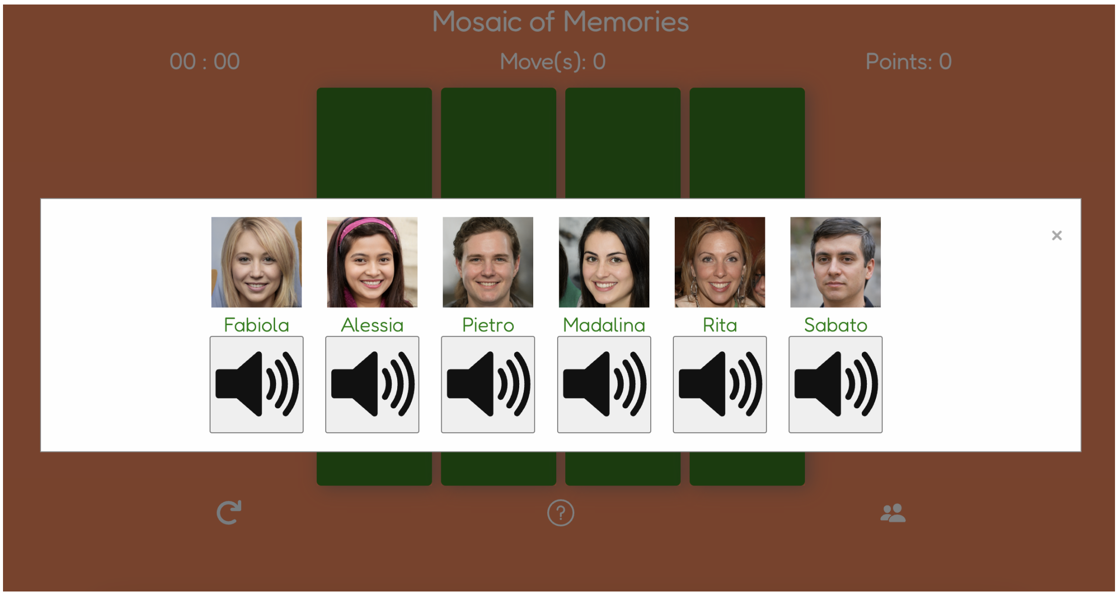

Figure 3: List of cherished individuals, showcasing their names and the audio recording.

- **New Game button:** Starts a new game by randomly rearranging the cards and resetting the score of player. As shown in figure 2
- **Help button:** It becomes clickable after the player has made three mistakes and, once clicked, suggests a correct move, temporarily revealing two equal cards after which it becomes unusable again. As shown in figure 4
- **Cherished individuals button:** Allows the player to display the card of all cherished individuals, showing the name of the loved one their photo and a short audio of the loved one's voice. As shown in figure 3

3.3. Game Steps

1. The player starts by clicking on the 'New Game' button.
2. The player turns over two cards at a time, trying to find matching pairs of cherished individuals faces.
3. If the player makes a correct match, the cards remain face up, the player earns a point and a pop-up is displayed showing the picture and name of the corresponding cherished individual. As shown in figure 5
4. If the player makes a mistake, the cards are covered again and the score is not affected.
5. If three consecutive mistakes are made, the "Help" button becomes available and, if clicked, suggests a correct match. After pressing the button, it again becomes disabled until the player makes three consecutive mistakes again, as shown in figure 4.
6. The game continues until all pairs have been found.
7. Game statistics are recorded to monitor progress over time.

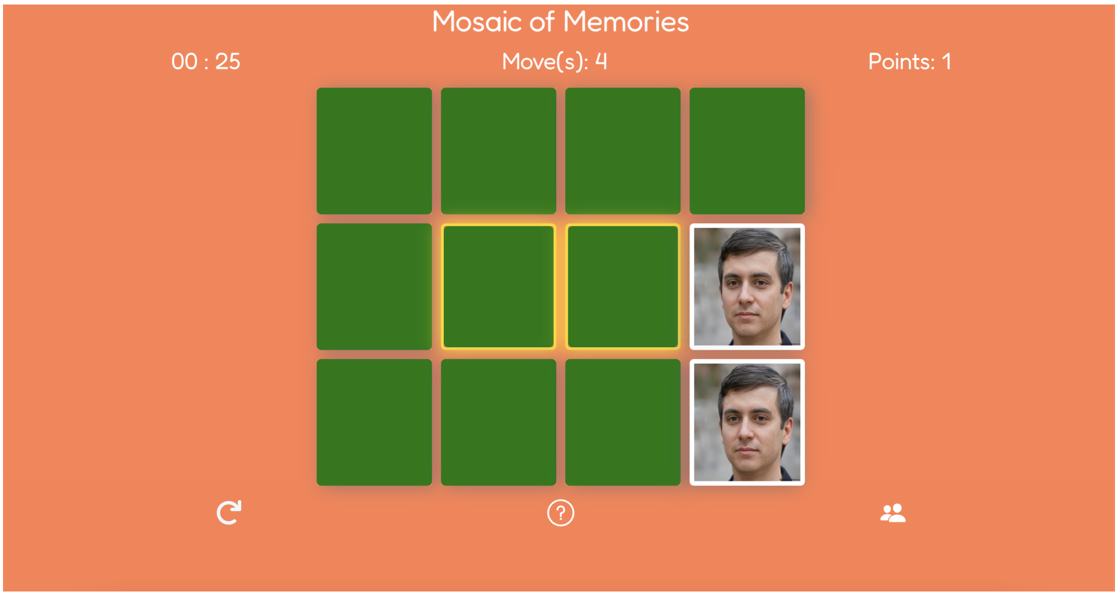

Figure 4: Utilization of help feature, can be activated only after 3 errors.

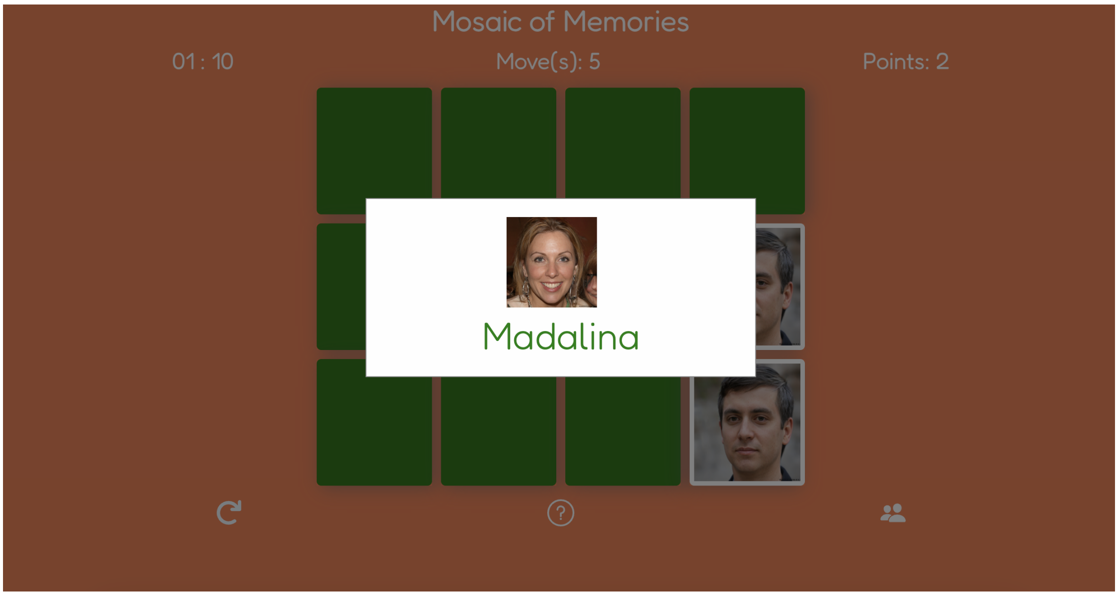

Figure 5: The window that appears when making a correct pairing shows the photograph and the name of a loved one.

3.4. Admin interface

The administrative interface is explicitly dedicated to a cherished individual or therapist of the AD patient and provides complete control over game settings and functionality (figure 7). The game experience can be customized to fit the patient's needs in this mode. Available features include:

- the ability to add or remove cards with pictures, names, and audio of relatives or loved ones;
- adjusting the difficulty level of the game by adapting the cognitive challenge to the patient's abilities and progress. As seen in figure 7, the administrator can choose three different difficulty levels that can be selected manually (easy, medium, expert) or the automatic mode can be selected, which provides the automatic adaptation of the game to the user's abilities;
- change the colors of the cards and background to accommodate patient-specific preferences or needs (e.g., color blindness).

In addition, as shown in figure 6, the system carefully records and stores data from each game session, which consists of the following: (a) games played, (b) games completed, (c) average frustration rate, (d) aids used, (e) averages of game times, and (f) number of games played by difficulty. These features allow caregivers to monitor the patient's progress over time.

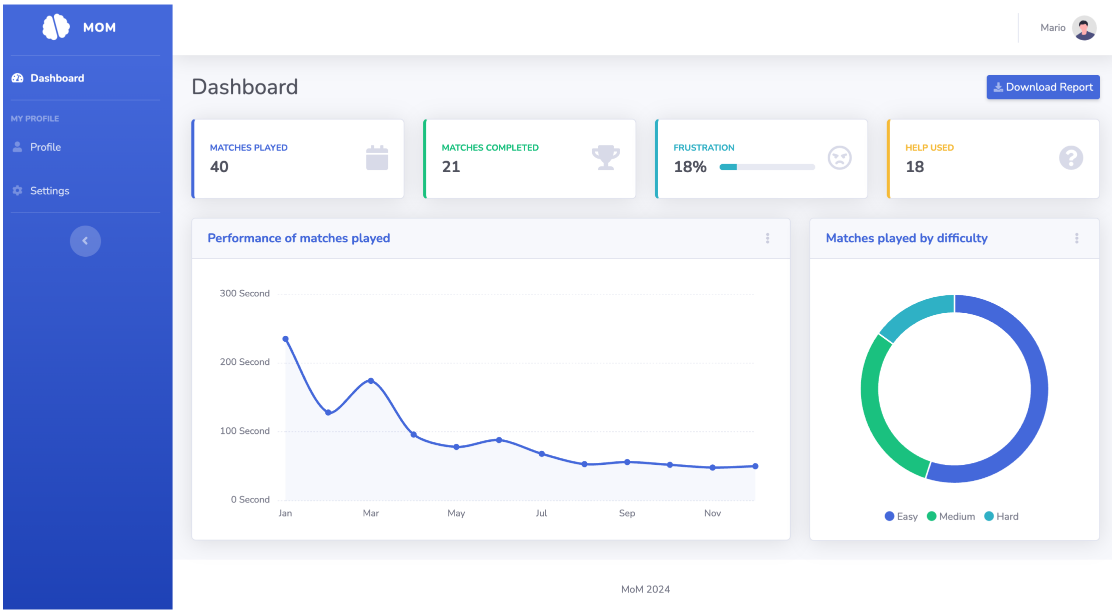

Figure 6: Dashboard of the admin application including: (a) games played, (b) games completed, (c) average frustration rate, (d) help utilized, (e) average playtimes, and (f) games played per difficulty level.

3.4.1. Handling user frustration

If users experience high frustration levels during game sessions, this can negatively affect the gaming experience, leading to anger and stress [55].
For this reason, MoM, a system designed to enhance the gaming experience, provides prompts when the player makes three consecutive errors during the game session. This feature is aimed

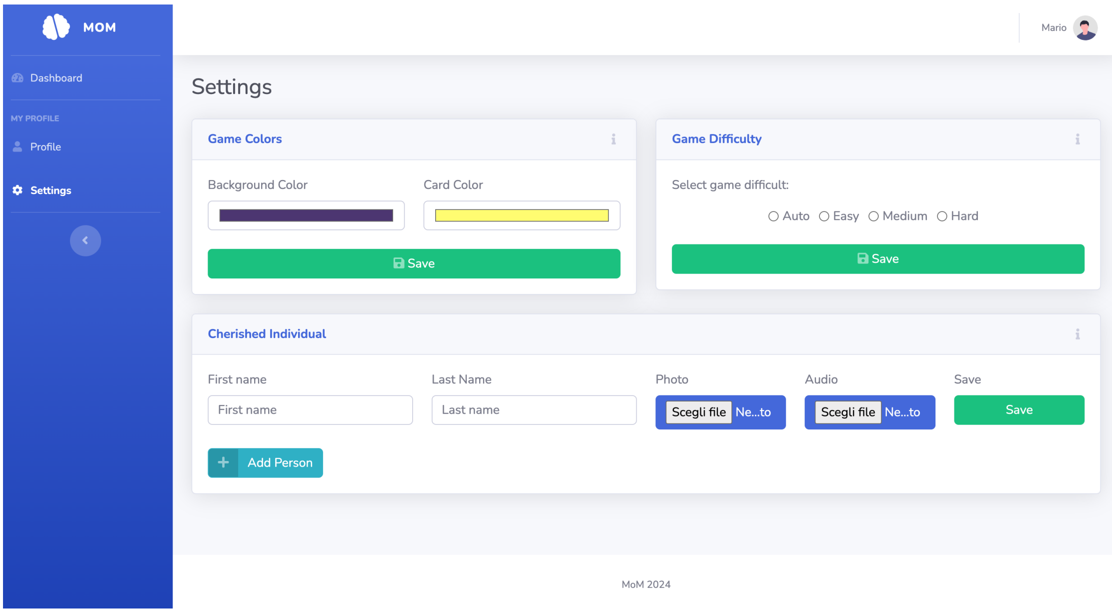

Figure 7: Customizable settings tailored to meet the patient's needs, such as difficulty levels, card and background colors, and inclusion of cherished individuals in the interface.

at reducing and mitigating the feeling of frustration, thereby improving the overall gaming experience. The literature shows that user frustration during learning tasks positively correlates with a specific mean intensity of facial micro-expressions, namely Action Unit (AU) 4 [56], which corresponds to the *Brow Lowerer* micro-expression. Therefore, we used the AU R-CNN model presented in [57], which aims to detect facial micro-expressions using a multi-label classification approach to address the complexities of facial expression analysis. Unlike standard R-CNNs, which may have difficulty capturing subtle changes in appearance in highly structured images such as human faces, AU R-CNN exploits prior expert knowledge encoded by the Facial Action Coding System (FACS) [58].

4. Conclusions

In conclusion, our proposed serious game represents a computerized cognitive training (CCT) designed for people with Alzheimer's disease (AD) to slow cognitive impairment of spatial and autobiographical memory. Taking advantage of the dynamic and interactive nature of the game, MoM is proposed as a tool to support the cognitive rehabilitation of patients with AD while promoting emotional well-being through personalized content. The adaptability of the game and its user-centered design allows for the creation of tailored experiences that adapt to individual needs and progress. However, to refine and optimize the system, future developments will involve a testing phase with actual patients and gathering feedback from mental health professionals. In addition, to validate the therapeutic efficacy of the serious game, it will be necessary to compare patients' performance at the game over time and the results of specific neuropsychological tests to assess autobiographical and spatial memory. This approach will provide a better understanding of the impact of the game on cognitive functions of patients and provide concrete evidence of its therapeutic efficacy.

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