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DEVELOPPING SERIOUS GAMES FOR COGNITIVE TRAINING:

DESIGN, INTERFACES, CHALLENGES AND ALGORITHMS

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CHAPTER 1

VIDEO GAMES FOR COGNITIVE TRAINING OF MENTALLY-IMPARED PATIENTS

1.1 INTRODUCTION

In the past decade, the video game industry has been developing and pushing technology to constantly offer players new, breathtaking experiences. The industry has been driving technology to create new hardware, achieve better performance, offer never seen before graphics and defining new ways for players to evolve in these virtual worlds. With over 155 million Americans playing video games, over 22 billion USD spent on the game industry in the U.S. in 2014 and more than half of U.S. Households owning a dedicated game console (ESA Essential Facts, 2015), it's clear that this industry is a huge success with games now being ubiquitous in our culture. But what exactly could explain this tremendous success that video games are being part of?

1.2 THE PSYCHOLOGY OF FUN IN VIDEO GAMES

Back in the mid-1970s, Minhály Csíkszentmihályi, a professor in psychology, came up with the concept of Flow in an effort to explain happiness (Csíkszentmihályi, 1990). This concept, which has since become fundamental to the field of positive psychology, has been originally described as a feeling of complete and energized focus in an activity, with a high level of enjoyment and fulfilment, also described as being “In the Zone”. In video games, Flow is a well-known concept characterized by the immersion of the player loosing track of time and external pressure, by the feeling of control over the game experience, the sense of disconnecting from everyday life, and the sense of disappearing (Chen, 2007). Jenova Chen explains that in order for a game to have broader appeal than others, their design must evoke positive feeling. He also explains that in order to maintain a user Flow's experience, the activity must balance the inherent challenge of the activity and the player's ability to overcome it, as shown in figure 1. If the challenge is too difficult for the player's skills, he will be overwhelmed and is likely to experience anxiety. On the other hand, if the challenge is too simple for the player's skills, he will experience boredom. In both situations, the player won't be in his Flow zone and may lose interest in playing the game.

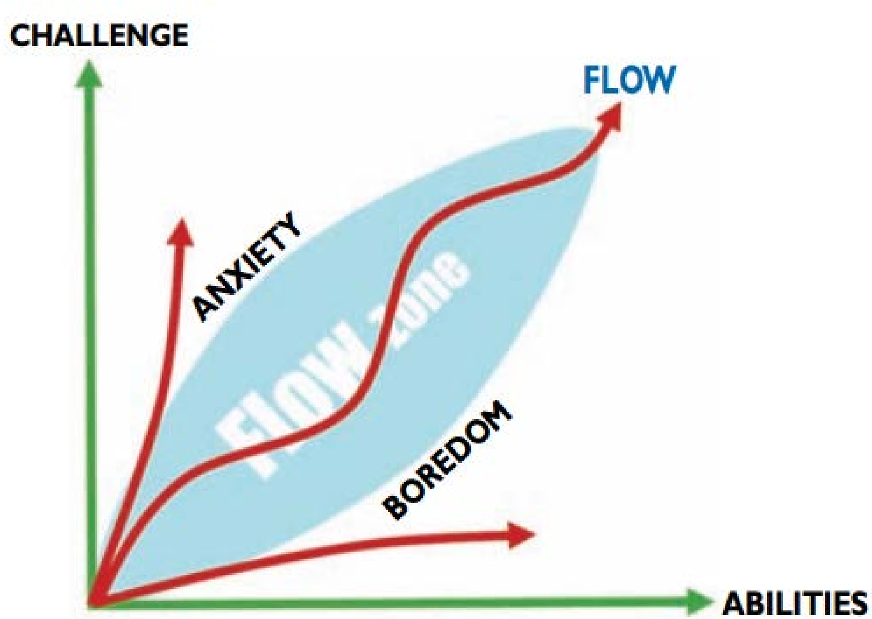

Figure 1 : Flow Zone factors.
(CHEN, J. « Flow in Games », Communications on the ACM, vol. 50, no. 4, April 2007)

However, while playing a given video game, different players will present different skill levels and won't require the same level of challenge to experience Flow. Many games have been trying to overcome this situation by offering the player a choice from different difficulties at the beginning of the experience. One way of doing this is by requesting the player to choose a difficulty from a defined set, such as easy, medium or hard. Those difficulty levels would be intimately bound to the skill level necessary to overcome the challenges that will be presented to the players. However, this often requires the player to guess their skill level before even trying the game. This can lead to frustration since the player can easily make a choice that won't correctly reflect the level of challenge that would suit his skills (Chen, 2007). Another way of approaching the different skills level problem is to implement Dynamic Difficulty Adjustment (DDA) into the game. DDA is a method allowing the game to dynamically modulate the difficulty of the different challenges in order to more accurately respond to the player's skill level through the course of a game session (Hunicke, 2005). Examples of DDA includes design-based approaches, such as letting the player control the difficulty of the challenges by their actions, as proposed by Chen (Chen, 2007). In that sense, Chen gives the example of real life surfers developing skills and choosing to engage particular waves. Other approaches such as the one proposed by Hunicke (Hunicke and Chapman, 2004) presents a computational way of determining the player's expectation of the difficulty in order to adapt the game to it. Independent of the approach used, the idea of DDA is to adapt the game to the player's skill level rather than asking the player to adapt himself. The result is more accurate challenges difficulty adapted to a wide range of players.

1.3 "SERIOUSLY" FUN GAMES

Over the past decades, the always increasing popularity of video games as an entertainment medium had many researchers wondering about its potential as a tool in many fields, such as promoting healthy behavior in children (Majumdar et al., 2013), supporting rehabilitation in disabled patients (Prange et al., 2015), training medical personnel (Graafland et al., 2012, Graafland et al. 2014), increasing social awareness (Rebolledo-Mendez et al., 2009) and using Game-Based Learning as an education tool (Egenfeldt-Nielsen et al., 2011). Still using the potential of high enjoyment, these games are built for a primary purpose other than pure entertainment. The concept of *Serious Games* was first described by Abt (Abt, 1970), as games that "have an explicit and carefully though-out educational purpose and are not intended to be played primarily for amusement". Early examples of serious video games includes The Oregon Trail (Rawitsch, 1978), produced in 1974 and designed to teach players about the life of 19th century American pioneers. In 1981, Atari developed The Bradley Trainer (Arcade-History, 2015), a game for the training of American army recruits in how to operate a Bradley tank. While the early era of serious games was mainly focused on military training (Laamarti et al., 2014), today's application are a lot broader. Ranging from education, health care, training and many other fields, the research on serious games has been rapidly growing in the past decade.

1.4 THE AGING OF WESTERN POPULATION

In the past years, research on neurodegenerative disease such as Alzheimer's disease (AD) increased significantly due to the urgency of the aging population. One notable area of such research is increasing life quality and autonomy of cognitively-impaired patients using Smart Home (Bouchard et al., 2012). For instance, the LIARA has been driving researches on activity recognition (AR) of AD patients in smart homes, using recent advances in artificial intelligence (AI) (Maitre et al. 2015, Tremblay et al. 2015, Fortin-Simard, 2015) and effective way to assists those patients in completing daily tasks by making efficient use of prompts to provide customized guidance as needed (VanTassel et al., 2011). In fact, studies have shown that it is more beneficial for AD patients to be provided with help in the completion of a given task than to simply see the task fail (Pigot et al., 2003). Further researches also shows that not only providing help in the completion of tasks will increase autonomy of AD patients, but specifically adapted use of different prompts, depending on the patient’s profile and nature of task, will increase efficiency of guidance (Lapointe et al., 2013). For example, auditory feedback can be adapted to certain profiles, but should be avoided with patients suffering from auditory disorder.

Another area that researchers have been exploring to overcome the aging of western population is to develop ways to cognitively train elders. To that end, some researchers have been driving efforts to develop tools such as close-to-reality simulation (Hofmann et al., 2003) or to make use of commercial games (Nacke et al., 2009) in order to train AD patient's cognitive abilities. However, none of these approaches takes into account researches in cognitive performance for AD patients, showing that specialized training should focus on four cognitive spheres: memory, planning skills, initiative and perseverance (Baum and Edwards, 1993) Furthermore, those approaches either does not make use of any assistance or does not take into account recent researches in Smart Homes in terms of adapted assistance depending on the patient's profile. Tools aimed at training AD patients cognitive skills should take into account all of these specificities in order to maximize its potential.

1.5 SERIOUS GAMES IN HELP OF AD PATIENTS

Seeing the enormous popularity of video games and the recent successful use of serious games in various spheres of application, we have been interested in accessing their potential for cognitive training of mentally-impaired patients such as AD. In that sense, our first paper (Imbeault et al., 2011) focused on using state of the art AI developed in Smart Homes for AR and assistance to develop a serious game prototype aimed at stimulating cognitive spheres of AD patients for cognitive training. The paper first introduces related work in the field of serious games and cognitive training of AD patients. It then presents our theoretical contribution, the in-depth description of a serious game prototype aimed at the cognitive training of AD patients. We describe the reasons behind design choices of the game settings and mechanics and also detail our different systems such as our DDA algorithm, the player's profile adaptation for adapted assistance during challenges, and the in-game cognitive evaluation. Finally, it describes our implementation realized to test our concept and exposes our efforts to conduct experimentations, with a description of our experimental protocol to be used.

CHAPTER 2

SERIOUS GAMES IN COGNITIVE TRAINING FOR ALZHEIMER'S PATIENTS

Serious Games in Cognitive Training for Alzheimer’s Patients

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***Abstract*—Research on progressive dementia increased significantly in the past years due to the urgency of the aging population. Patients suffering from such dementia, for instance Alzheimer's disease, lose efficiency in cognitive spheres such as memory, planning skills, initiative and perseverance. Some researchers tried to evaluate the potential of close-to-reality simulations and generic video games for brain training to stimulate the cognitive abilities of AD patients. Using recent advances in artificial intelligence such as learning, activity recognition and guidance to enhance this concept of training, we are proposing, in this paper, a detailed explanation of an adapted serious game we designed for this purpose. A prototype has been developed showing how to exploit AI techniques to create an affordable and accessible tool for cognitive training and allowing in-game estimation of the patient's cognitive performance.**

Keywords-algorithms; design; human factors; cognitive training; cognitive performance; serious game; alzheimer's disease; cognitive impairment;

I. Introduction

Over years, the game industry created new platforms, such as the Nintendo Wii and the Nintendo DS, in order to attract a larger community of gamers. Theses platforms present new ways of gaming, enabling the entire family to play together. Constant evolution in these technologies recently paved the way for what is called serious video games. This new type of digital games specializes in other purposes than just entertaining, such as educating [1], leading societal impact on specific subjects [2], enhance individual user's aptitudes [3] and, more recently, train cognitive faculties of silver-aged gamers [4]. Recently, research on progressive cognitive dementia like Alzheimer's disease (AD) increased significantly due to the aging of the population. Some researchers turned themselves towards serious video games, in order to measure their potential in cognitive training of silver-aged gamers and AD patients. To explore this potential, most of the studies either use a realistic approach using close-to-reality simulations [5], or serious video games made for this purpose [4]. Nevertheless, AD patients need specialized training that will focus on four cognitive spheres; memory, planning skills, initiative and perseverance [6]. In addition, AD patients need specifically adapted challenges, and also need help to complete them. In that sense, studies show that it is more beneficial for AD patients to be helped through completion of a given task than just see the task failed and be presented with a new challenge [7]. Thus, to be correctly suited to this type of patient, a serious game should remain non-intrusive and present assistance to the patient through completion of the challenges. Moreover, each patient presents a different profile and might not necessarily need assistance in the same contexts or even in the same manner [8]. For example, a patient suffering from auditory disorders can benefit from a visual feedback, but auditory feedbacks should be avoided. Consequently, trainings should dynamically adapt themselves to a given profile to be fully effective. Yet, most games on cognitive training such as the popular Nintendo DS game Dr. Kawashima's Brain Training does not offer either help to the player in the completion of challenges or dynamic adaptation to the player's profile. Therefore, not only these games are not suited to this kind of player, but they does not allow the players to think about their errors and try to correct them, which is an important point in education and re-education [9]. We also noticed that the tools used in previous research [2,4,5] does not make use of modern artificial intelligence technologies such as learning, activity recognition (AR) and guidance in order to offer a personalized and more effective experience.

Considering these problems and in order to contribute to the researches on cognitive training of AD patients, we are proposing, in this paper, the design and prototype of a serious game toggled to these patients. The prototype show how to exploit the recent advances in AI techniques to create a game that will constitute a cheap and accessible tool for AD patient's cognitive training and evaluation. The tool will also enable researchers to compare standard cognitive games to such specialized serious games. As for a gym can be used to train our body 3 or 4 times a week using specific equipment, the game will provide cognitive tasks and challenges to train mental faculties and help to slow down the degenerative process of cognitive functions of AD patients. Previous contributions of our labs, such as an AR model for AD patients [10], trial data sets for smart home researchers [11], and adaptive game mechanics for learning purposes [9] will be used to design and develop the game.

This paper is organized as follows. Section 2 introduces the relevant related works in serious video games and cognitive training in Alzheimer's disease. Section 3 brings forward our theoretical contribution, including the conceptual model of the game. Section 4 describes the implementation realized to test our concept and presents technical aspects of the game. Section 5 exposes our ongoing efforts to conduct experimentations and describes our experimental protocol to be used. Finally, Section 6 presents the conclusion and perspectives of this work.

II. RELATED WORKS

Since the last few years, a lot of effort was done in order to study the different cognitive dementia related to the aging of the population. A lot of research focused on finding and testing new ways of training the cognitive functions of elders by creating simulations or using video games to evaluate their potential [2,4,5].

For instance, Nacke et Al. [4] tried to answer to the following question: "Are new ubiquitous technologies and media forms, like digital games on portable consoles, a blessing or a curse for an aging Western civilization?" They conducted research on positive gameplay experiences provided to this aging population. The paper suggests that "players, regardless of age, are more effective and efficient using pen-and-paper than using a Nintendo DS console. However, the game is more fun and induces a heightened sense of *flow* in digital form for gamers of all ages" [4]. Flow represents the feeling of complete and energized focus in an activity, with a high level of enjoyment and fulfillment [12]. In video games this is characterized by the immersion of the player loosing track of time and external pressure, by the feeling of control over the game he experience, the sense of disconnecting from everyday life, and the sense of disappearing [9,12]. In order to achieve this state of mind, a game must present four elements; clear goals, constant feedback, possibility to focus on tasks, and possibility to complete tasks [9,12]. The research also suggests that elderly might prefer a game that elicits positive emotions and tense feelings rather than excitement and difficult challenge. In other words, the game need to present an adapted difficulty and the player must be positively rewarded in order to provide a nice gameplay experience. Achieving this will make the game more fun for elderly gamers, improving their learning experience [13]. However, the presented research used the popular Nintendo DS game Dr. Kawashima's Brain Training to calculate positive experience on elderly gamers, which do not offer either help to the player in the completion of challenges or dynamic adaptation to the player's profile. Besides, the game use a touch-screen system, which silver-aged gamers may not be familiar with, thus, it could false efficiency and effectiveness variables.

Hofmann et Al. [5] conducted an experiment on interactive computer-training as a therapeutic tool in Alzheimer's disease using a close-to-reality simulation of a shopping route. An interesting point of the experiment is that training was well perceived by AD patients, even though it could have been feared. Moreover, the study showed that a significant improvement in mistakes has been observed during the training. After a 4 week period of training, the patients had a 3 week period without exercise. Yet, no difference was observed between the week 4 training results and the follow-up examination at week 7, which reveal that the training benefits were sustained over a period of 3 weeks without exercise. Consequently, cognitive training in degenerative cognitive disorders is an important field of study, as it can help patients to improve their cognitive skills. Using this information, we want to know if reaching a Flow state during a play session, by creating a fun environment in which the patients can evolve, will improve the results of cognitive performance, compared to realistic simulations.

Finally, a research made on the potential of educating with serious video games was conducted by Rebolledo-Mendez et Al. [2]. They presented a game called *FloodSim* and evaluated the societal impact of a simulation-based game, proposing that "Role play is a powerful tool for behavioral change". In fact, the paper suggested that their simulation increased awareness at a basic level and that serious games have the "potential to engage the public" by education. Their research does not refer to cognitive dementia or the aging of the population, but proves the educational power of serious video games and their possible impact on an entire society.

In conclusion, several experiments used serious video games and simulations to measure their educational power and the possibility of using them for slowing down the degenerative process of cognitive functions in dementia like AD. However, none of these projects made use of modern advancement in artificial intelligence to offer a more effective training and allow an in-game estimated evaluation of the patient's cognitive abilities.

III. DESIGNING A GAME SUITED FOR AD PATIENT

Recent research, as we just saw, tried to evaluate the potential of serious video games. They finally all came to the conclusion that such games can be used in their specific context as they have an interesting education and training faculty, and generate more arousal and flow than pen-and-paper games. This is caused by the pleasure generated from video games, which creates a motivation for the player to learn from the game [14,15]. Thus, it endorses our choice for developing a serious video game to train cognitive abilities of AD patients. In order to create such a game, we need to design a game concept that is correctly suited to the patients.

A. Game design: Choosing the right challenges

First, the game needs to be very straightforward and easy to learn to avoid confusion. Therefore the challenges presented must reflect the patient’s everyday life, in order to avoid the need of understanding complex mechanisms. To do this, we need to recreate a well-known environment of the patients, and introduce challenges familiar to them [11]. Secondly, we need to be able to provide adequate feedbacks through the game in order to help the patients during the different challenges [16,17]. Third, we want the game to be capable of estimating the cognitive abilities of the patients through the play sessions, using the data collected from the different activities. This will allow us to measure the positive impact of the game on the patient’s cognitive performance through the training sessions, and keep a history of the estimations through time to fully evaluate the game potential. Finally, we need to define a correct number of steps for each game’s levels. This number must be high enough to correctly train the cognitive abilities of the patients. However, too

Figure 1. Experimentations at our lab: An AD patient performing the NAT.

much steps could overload them and lower the benefits of the game.

For testing real-life patient's cognitive abilities, our lab is using a well-established neuropsychological test called the *Naturalistic Action Test* (NAT) [18]. The test uses adapted activities based on routines actions of everyday life called *Activities of Daily Living* (ADL), in order to assess the patient's errors using predefined score sheets, as shown in Figure 1. We decided to develop a game concept based on the activities used in this test, and to integrate the score sheets used to evaluate the patients, in order to analyse the patient's actions while they are facing the proposed challenges, and give a fast estimation of the patient's cognitive abilities during the play session. Therefore, we aimed for game levels made of 8 to 12 steps for completion, to assure they would be compatible with the NAT.

Considering these constraints, we decided to base our serious game concept on cooking activities. These are the reasons why we chose this kind of activity: First, they respond the need of recreating a well-known environment for all patients [11]. Secondly, the NAT tests we are using with real patients are mostly done in a kitchen environment, so the integration in game will be easier since there is plenty of accessible data on the subject. Besides this, the importance of food in everyday life is quite crucial. Thus, not only that making the patients prepare toasts and coffee will train their cognitive faculties, but it will also make them able to repeat such tasks outside the training, i.e., at home [11]. Finally, cooking is a well-established subject in ADL [10], which means we can access plenty of information on this topic, allowing us to easily evaluate the patient through the training process.

B. Game software architecture

As seen in the previous section, some constraints needed to be considered in order to choose the right challenges to be presented to the AD patients. This is also true for the design of the game software architecture as well. First, we need a game that will correctly train the AD patient's cognitive abilities, and adapt itself to their evolution. Then, we need the algorithmic model to be capable of dynamically estimate the cognitive performances of the patients during the play sessions, without interrupting the training, as explained in section 3.1. Finally, we need to provide feedbacks to the patients through the game in order to help them in the completion of the game levels. However, theses feedbacks must be correctly adapted to the patient's profiles in order to be relevant [8]. Figure 2 shows the software architecture of the proposed prototype game.

1) Patient's profile adaptations: In figure 2, we can see that section A of the software architecture includes two game modules, which are the Profile Analyser and the Feedback Module, as well as an external data collection containing relevant information on the patients, which is the Player Profile. This section will significantly enhance the effectiveness of the training, by adapting two key modules of our game; the Feedback Module and the Error Checking Module.

First, a unique player profile is created for each patient, built from clinical trials using a designed experiment based on the NAT [11]. This profile contains relevant data about the patient and will be used to analyse his evolution through the trainings. First, it contains an evaluation of his four cognitive spheres, which are memory, planning skills, initiative and perseverance. Then, it also includes an evaluation of the patient's aptitudes to use his different senses, in order to give a tool to the game in choosing the right feedback to provide. Finally, the profile also contains relevant data about the patient's normal performance for a set of activities, such as his normal completion time for each step and for completing the activity, his usual step order,

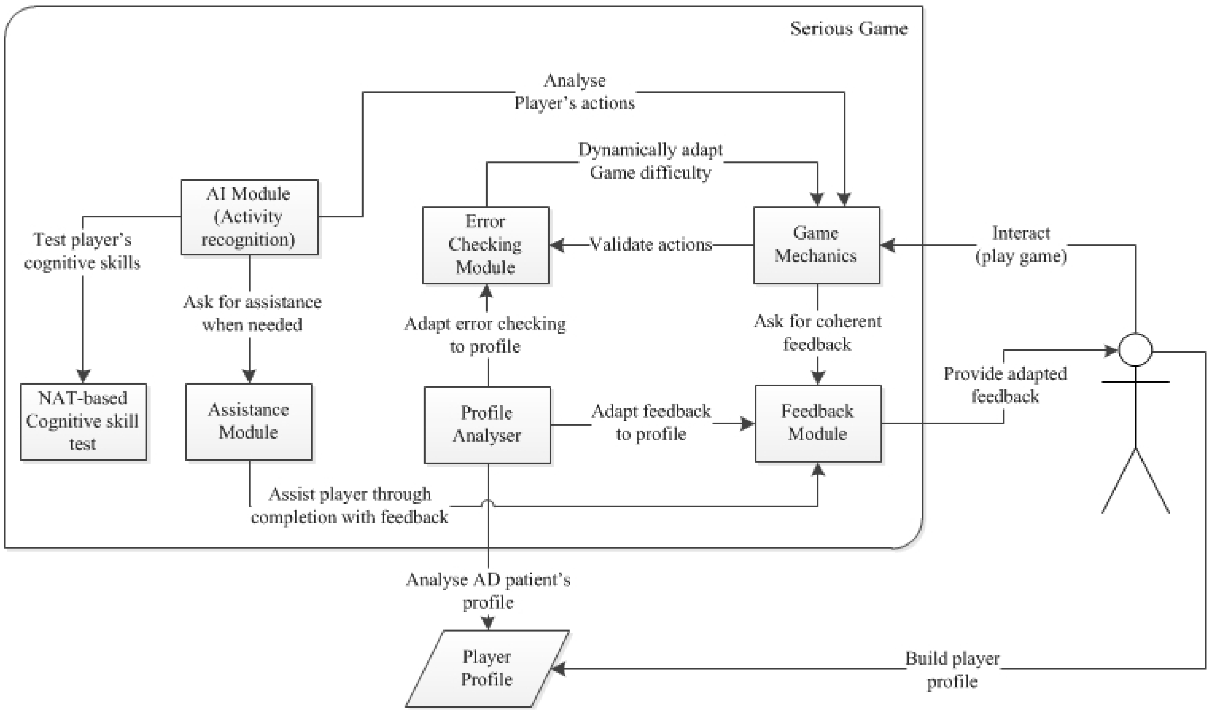

Figure 2. Game software architecture.

frequent errors committed, common hesitations, etc. All this information forms the *Player Profile* data collection. These data are not bound to the game and can be used in other experiments of our lab. Next, the *Profile Analyser* module interprets the data from the profile to be used for this play session. These data will first impact on the *Feedback Module*, also based on previous lab works [8], in order to rate available feedbacks and offer optimal assistance to the patient through the completion of the game levels. For instance, if it is written in a given player profile that the patient suffers from auditory disorders, the game will then rate visual feedbacks higher than auditory feedbacks. Compiling the different information in the player's profile, the game will finally choose the best available feedback to help the patient when needed. Finally, the *Error Checking Module* will also be adjusted to provide a personalized analyse of the patient's errors [19], as well as allowing a better understanding of positive or negative evolution of the patient's cognitive abilities through the training process. The impact of this adjustment will be further explained in section II, B., 3).

2) Activity recognition for dynamic assistance and cognitive abilities estimation: The section B of our architecture uses modern artificial intelligence algorithms to define its modules and their interactions. This component contains three modules.

Considering that a given task can be carried out in many different ways, we must be aware that the different tasks presented in the game can be correctly completed by the patients, even if the order of some actions is not the same from a patient to another. For example, a patient could add sugar to his coffee and then add milk before steering, while another would chose to add milk before sugar. In fact, the result obtained in these situations is the same, and thus, the tasks execution must be considered as correctly completed in each case. However, a patient could not chose to butter his bread slices before toasting them, as it would not lead to the same result of the correct pattern, which is toasting the bread slices before buttering them. Considering this, we need a module in the game, responsible of analysing the patient's actions in order to determine which action he initiated, and determine if the following actions are done in a proper way. Finally, since we are experimenting with real AD patients, we must further be aware of an important problematic in the assistance of cognitively impaired patients: an unexpected action cannot be directly interpreted as an error, as it could be part of a new plan initiated by the patient, carried out in an interleaved way. However, this action could indeed be an error, in which case it should be interpreted as it. This problematic is called the interleaved-erroneous dilemma [20]. The *Activity Recognition Module* makes use of recent advance in artificial intelligence to determine whether the action undertaken by the patient can still lead him to the completion of his task or should be interpreted as an error [21]. The module works using description logic [22] and a hybrid between probabilistic and fuzzy logic called possibility theory, in order to transform the recognition problem into a possibilistic classification of activities [21]. Unlike the probability theory, possibility theory is non-additive and allows us to capture the fact that an erroneous behavior hypothesis is as possible as a normal behavior hypothesis when observing a patient carrying out an activity. Hence, our recognition algorithm is capable of detecting whether an action undertaken by a patient is an error or, in the opposite, an action part of another plan started in an interleaved way [20]. This analyse will be necessary for the *Assistance Module* and the *NAT-Based Cognitive Test Module*, as detailed in the subsequent section.

The second part of the section B is the *Assistance Module*. This module uses the analysis provided by the activity recognition module and the player profile to determine on what action the assistance should be focused. However, the module needs to create a solution conform to the strategy used by the patient [23] and which fit his profile information, such as his usual step order for a given task. In addition, the form of guidance must be adapted to the patient characteristics [8], in order to provide coherent feedback. The module use a library of plans created using description logic [22] to match his guidance to the patient's strategy.

The last part of section B of our game architecture is the *NAT-Based Cognitive Skill Test*. This last module use the results from the activity recognition module to fill the score sheets integrated in the game, explained in section 3.1, to give an in-game estimation of the patient's cognitive abilities. This estimation will allow us to follow the evolution of the patients through the training process and rate the challenges by measuring the positive impact of playing them once or multiple times during a defined time period.

3) Dynamic difficulty adjustment (DDA): Section C is the last part of our model. First it contains the Error Checking Module, which is in charge of detecting user's errors, rate their frequency through the different game levels, and rate their importance. Section C also presents the Game Mechanics, which regroups all the mechanics needed to create the interactions between the game and the patients, such as grabbing an object or displaying information. By creating an interaction between those two modules, we can interpret the patient's errors and then, when similar errors are done within a short period of time, the error module can inform the game mechanics that the difficulty of the level should be revised. That in-game difficulty revision is called Dynamic Difficulty Adjustment (DDA).

Most commercial video games present a list of difficulties to choose from to suit every type of players (i.e. hard, normal, and easy). Still, this method is relatively static, and the player needs to correctly fit in one of those (and yet, they must choose the right one before they even get a chance to try the game). DDA is a method that offers an alternative to mismatches between player skills and game challenges. It modulates in-game systems to respond to a particular player's abilities over the course of a game session [24]. In the case of our game, this is reflected by offering more or less help to the patients when they encounter difficulties related to their cognitive skills. More precisely, we are using an algorithm, based on the *ELO* system designed by Arpad Elo [25], which ranks the players depending on their in-game performance [26]. The *ELO* system makes use of the normal distribution function *FN* to predict the overcome of a match between two players based on their respective relative skill levels. Given two player's rank *R1* and *R2*, the expectation value is calculated by evaluating the normal distribution of the skills difference *FN(R2 – R1)*. Hence, the greater the difference between the player ranks, the higher the expectation value is for the highest ranked player. Since our game is only played in solo mode, the player gets to compete against the game itself. To achieve this, each game level is also given a value, similar to the player ranks, which acts like the *level difficulty* value. Then, the relative skill level of the player is compared to the game level difficulty using the normal distribution function, in order to calculate a *difficulty ratio*. This ratio represents the challenge to be experienced by the player when trying to accomplish the tasks presented in a single game level. Consequently, a player with higher skill will need to face a challenge more difficult than the one faced by a less skilled player in order to experience the same challenge. During the trainings, the player ranks will be adjusted as the patients evolve through the game, and this ranking will be used to define the level of help provided by the assistance module. For instance, if the average players rank of our system is 1400 and a given patient makes no errors for many consecutive actions, his ranking could increase to 1800. Later on, if the same patient makes an error, it will slightly decrease his ranking. As a result, the assistance module will give him less help since he still have a great ranking. However, if the patient repeats errors, his rank will drop, making the game assist him more in the completion of his task. Finally, when a level is finished, the player rank will be analysed to adjust the next level difficulty value in order to attain the desired difficulty ratio. This creates a system which makes sure the patients are always facing challenges adapted to their skills.

An important impact of the usage of DDA in our game is that it will generate *flow* during the trainings. For instance, if a patient takes time reacting to given feedbacks when he makes errors because they are vague and infrequent, he will probably quickly get discouraged. In the opposite, a patient who receives too many information about the next logic action won't get to exploit his cognitive abilities to find the action on his own. Each of these two players will easily get bored after a few minutes of play because the challenge either fails to engage the player, or is beyond his abilities [12]. However, adjusting the difficulty by controlling the amount of feedbacks provided and their precision will adjust the challenge, and thus, replace boredom and anxiety with pleasure. This should also have a great impact on the re-education experience. In fact, previous research on enjoyable learning made in nursing and midwifery education [13] showed that if a student considers a lecture enjoyable, they will be more interested and motivated to learn, which is fundamental in adult learning. The paper suggests that fun activities encourage deeper level of learning and offers a greater impact on the learning experience. To do this, they use the example of a game used to "teach theory while at the same time help students to develop skills in debate, critical thinking, clinical reasoning, resolution, and prioritization". Therefore, DDA will enhance the patient's experience, and hence, provide a better learning experience.

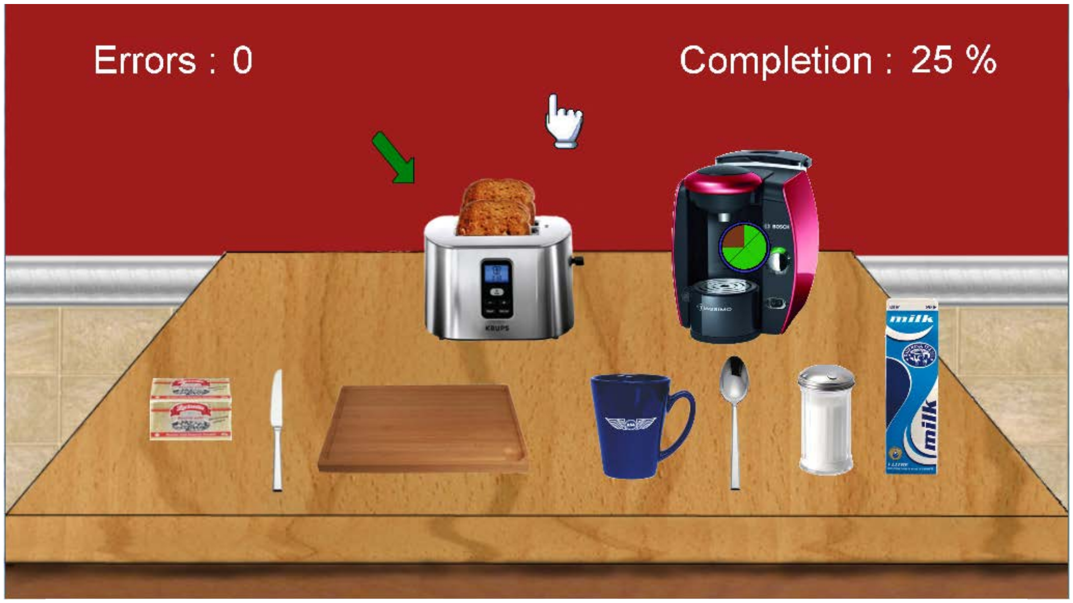

Figure 3. Our serious game prototype for AD patient's cognitive training.

IV. Implementation of a Prototype

A. Developing the game

Figure 3 presents a running screenshot of our game prototype. This prototype was built using the Torque Game Builder (TGB), a 2D game engine developed by Torque. The TGB engine offers two useful tools for game development we used for creation of our prototype. First, the level editor enables us to create objects, such as kitchen furniture, and place them in different scenes. We used this tool to stage the prototype levels and menus, set the different animations and define levels specifications. Then, we used Torsion, an IDE created to develop in Torquescript, a proprietary scripting language developed specifically for Torque technology, to create the object's behaviors and all game mechanics.

B. Gameplay

The game is a point-and-click, making it quite easy to handle and understand, even for elderly gamers who may not be familiar with video games. For example, the patient may click the bread slices with the hand cursor to grab them. The cursor will then change to provide correct feedback, and the toast will follow the cursor, as the object is now considered in the patient's hand. The patient may then click again on the toaster to put slices in, or lay down the object somewhere else. The action of taking an object is simple and quick. However, some actions may take time to complete before requesting the patient's attention, such as making coffee. Thus, it is possible to undertake multiple tasks at the same time (e.g., toasting bread and making coffee at the same time, as shown in figure 3). In this case, a timer asset would appear and display the remaining time before the task is completed. When it is finished, another feedback, depending of the patient's profile, would replace the timer to indicate which object requires attention. For example, we could place bread slices in toaster, and a timer would appear to show the remaining time while they get toasted. When they are ready, another feedback would appear (i.e., an animated arrow in the figure 3) to get the patient's attention on the object. These simple mechanisms make the game easy to understand and play.

V. Upcoming Experimentations

Actually, the game presented in section 4 is still in development. However, using the formal agreements between the lab and our clinical partners, we are planning upcoming experiments of the game. In fact, we have two formal agreements at our disposition we can use to obtain the collaboration of AD patients. The first one is with the *CSSS Cléophas-Claveau* of *Ville LaBaie*, a regional rehabilitation center which welcomes many AD patients and which is in charge of diagnosing all cognitively impaired patients in our region (pop. 150K). The last one is the *Maison LePhare* of *Jonquière*, a private center who provide permanent housing for AD patients. The experimental process will be divided in two major phases, as detailed in the present subsections.

A. Phase 1: Experimenting with trial data sets

This preliminary phase consist of using the data gathered from past experimentations with the NAT on AD patients. Using these data, a human actor will be able to simulate scenarios in order to test the game in various contexts. With this experiment, we will then be able to measure the relevance between these sessions and the results they generate, by rating the interactions between the game and the actor. With this information, we will have the resource necessary to make the adjustments to the different modules and assure the best performance of the game.

B. Phase 2: Experimenting with alzheimer's patients

In order to realize the second phase, we need to test the game in real situations. To achieve this, we are already taking measures to obtain the ethic certifications allowing us to recruit an adequate number of patients. We want to begin with a group of 20. For these experimentations, we will use a four-step experimental protocol, similar to our previous experimentations [8]. The first step consists of meeting each pairs of patients and the person who is assisting him, in order to familiarize them with the project and make them feel confident about it. In the second step, we will conduct a cognitive evaluation of the patients and create a profile for each of them to be used by the game for the training. In the final step we will test the game over a short-time period of 3 to 4 weeks with the patients by following pre-established scenarios. These test sessions will be observed and evaluated by a team of multidisciplinary experts, and will be filmed and conserved in our database for future experiments. Finally, all the patients will be evaluated at the end of the training period, and again 3 weeks after the end of this period. All data gathered by the game, i.e., actions, interactions, errors analysis, guidance, score sheets for cognitive abilities estimation and all other data considered useful, will also be conserved for future use. The experimentation team will be formed of experts and researchers in the field of neuropsychology, computing, artificial intelligence and cognitive assistance technologies, as well as University students studying psychology and video game development.

C. Analysing the experiments results

The experiments presented above will allow us to measure the power of serious video games in cognitive training, which is a promising new avenue of research. First we will verify the validity of our in-game cognitive abilities estimations, as it is a crucial tool in cognitive training, as well as in our game. This will be done by comparing data gathered from the game to real NAT results obtained for the same patients. Afterwards, we want to measure the positive impact of the training on the different AD patients. This will be done by analyzing and comparing the evaluations made before the training period to the one conducted just after this period. Finally, we want to test whether the results will be sustained after the training or not, by comparing the results of the evaluations made at the end of the training period to the ones conducted 3 weeks later. This will give us information on the possibility to train patients in a long-term vision. All useful data gathered from these experiments will also be used in further researches.

VI. Conclusion

Due to the urgency of the aging population, the researches on progressive cognitive dementia like Alzheimer's disease increased significantly. One of the promising new avenues of research is the training of cognitive abilities, for patients suffering of such dementia. In order to achieve this, AD patient's need specialized training that will aim four cognitive spheres, which are memory, planning skill, initiative and perseverance [6]. While other presented researches measure the potential of close-to-reality simulations and generic video games for brain training, we proposed, in this paper, the design and development of a serious video game created specifically for patients suffering from Alzheimer. Our design and prototype makes use of recent advances in the field of artificial intelligence such as activity recognition and guidance to offer optimal experience through the training sessions. We presented how we designed the game, first by explaining how we choose the right challenges in order to avoid the need of complex mechanisms and allow in-game estimation of the patient's cognitive performance using score sheets like the NAT. Then we explained our game software architecture steps by steps and described the prototype implemented in Torque Game Builder. Since the game is still in development, we explained our outgoing efforts for the experimentation of the game and exposed the different phases of the process. Our work will be beneficial as it will provide a cheap and accessible tool for further researches in cognitive training. Finally, we believe that further experimentations will clearly help to measure the power of adapted serious video games for the cognitive training of AD patients, and we hope that these researches will encourage further works on this new promising avenue.

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CHAPTER 3

TOWARDS GUIDELINES TO SERIOUS GAMES FOR COGNITIVE ASSISTANCE

3.1 INTRODUCTION

Our work up to the publication of the article presented in the second chapter mainly focussed on going through current state of the art in different fields of research to build an effective tool for the cognitive training of patients suffering from Alzheimer's disease (AD). Seeing the enormous success of video games in the past decades and the growing number of games built for another primary purpose than entertainment due to their effectiveness in different fields, it became clear to us that Serious Games would probably have great potential in cognitive training of AD patients. In order to effectively exploit this potential, we needed to understand how such a game would be built to respond to the needs of this particular audience. We studied the psychology of fun in video games and how the concept of Flow would help us keep the patients engaged in the experience, avoiding feelings such as anxiety and boredom (Chen, 2007). To do so, we explained how we adapted the well-know ELO raking system to create a DDA algorithm for a single player game, by having the player to score against the game itself. We also explain the importance of recreating a well-known environment to the patients and introduce them with challenges familiar to them. Furthermore, we expose our focus on assisting the patient throughout the different challenges using recent researches on using correct prompting for assistance based on the patient's profile and nature of task for cognitively-impaired patients.

Following the implementation of our first serious game prototype, we had seen multiple approaches for cognitive training of mentally-impaired people. However, these researches either did not make use of specifically adapted tools for AD patients or did not use the potential of serious games, which had been proven effective in many fields. In order to contribute to the scientific community, we felt the need of creating guidelines for the development of serious games specifically adapted for the cognitive assistance of AD patients. Those guidelines could then be used to create different serious games targeted at AD patients or be adjusted to target other cognitively-impaired patients. The set of guidelines we created for this purpose cover four different aspects: (i) choosing right in-game challenges, (ii) designing appropriate interaction mechanisms for cognitively impaired people, (iii) implementing artificial intelligence for providing adequate assistive prompting and dynamic difficulty adjustment, (iv) producing effective visual and auditory assets to maximize cognitive training. Each of these aspects are introduced in this chapter and covered in-depth in the article presented in chapter 4.

3.2 CHOOSING RIGHT IN-GAME CHALLENGES

Previous researches show that, in order to avoid the need of learning complex mechanisms, we need to recreate a well-known environment to the patients and present them with adapted and familiar challenges (Laprise et al., 2010). In order to be able to measure the positive impact of the training we also need to conduct in-game cognitive evaluation during play sessions. In that sense, our first guideline suggest choosing challenges that will allow evaluation, and keeping trace of the patient's cognitive abilities from data collected during play sessions. In our game, we chose to implement activities from the well-known neuropsychological test called the *Naturalistic Action Test* (NAT) (Schwartz et al., 2002), which uses adapted activities based on routine actions of everyday life called *Activities of Daily Living* (ADL). This also allowed us to integrate proven score sheets for cognitive evaluation of the NAT directly in our game. We then suggest determining an appropriate number of steps for the chosen challenges, as too much steps could overload the patients and lower the benefits of the training. Since we use NAT-based evaluation in our game, we made sure to have compatible levels presenting from 8 to 12 steps. As a third guideline, we suggest keeping the player in his Flow zone to maximize engagement and positive impact of the training. In that sense, it is important to remember that it is more difficult for AD patients to learn new paradigms or complex mechanisms. In order to avoid confusion or frustration, and induce an enjoyable experience, the game must be straightforward and easy to learn. Finally, the article exposes our choice of using cooking activities in our serious game and explains the reasons behind this decision.

3.3 DESIGNING USER INTERFACE AND INTERACTION MECHANISMS

In order to have a healthy brain, it is known that physical activities can have beneficial effects on cognition (Kramer et al., 2003, Hillman et al. 2008). Thus, physical activity should be used in conjunction of cognitive training to increase its positive effects. In that sense, our guidelines suggest to promote ecological interactions in the serious game in order to reduce the learning time for the patient and lead to greater enthusiasm and engagement. However, it is important to do so with the targeted group in mind. Since elderly people can suffer from impaired motor skills, interactions based on whole body should be avoided. We also suggest having light interface for home-based exercises, like having portable interfaces that does not require any particular skills for configuration at home. Finally, we suggest taking advantage of the multimodal aspect of virtual reality (VR) technologies. For example, by using voice to indicate commands, or using vibro-tactile feedback as a memory aid (Kuznetsov et al., 2009). This also enables us to modulate the experience based on the patient's profile, giving us multiple alternatives for people with auditory or visual disorder.

3.4 **AI FOR ASSISTIVE PROMPTING AND DYNAMIC DIFFICULTY ADJUSTMENT**

The concept of Flow in video games is the ability to induce a high level of enjoyment and fulfilment, resulting in greater engagement from the player, by creating a balance between the player's skill level and the difficulty of the challenges presented by the game (Chen, 2007). In order to maintain this balance, the game must adapt itself to the player by modulating the challenges to match the skills of the player (Hunicke, 2005). Since we are creating games for the silver-aged, it is important to keep in mind that they are not usually familiar with digital forms of games (Nacke et al., 2009). In that sense, we provide guidelines to use Dynamic Difficulty Adjustment (DDA) and assistive prompting to adapt serious games to AD patients. First, we propose to use Activity Recognition (AR) and the player's profile to provide adapted assistance. Video games may not require complex mathematical model such as POMDP (Mihailidis et al., 2007) or HMM (Wilson and Philipose, 2005) used in smart homes, but the game should be able to provide adapted assistance on the task the player chose to undertake. It is also important to make use of the player's profile in order to choose adequate assistance prompt (Lapointe et al., 2013). We then propose to make use of DDA to keep the player in his flow zone. In our game, we implemented an algorithm based on the well-known ELO ranking system (Coulom, 2010), adapted for a single-player game. To do this, we assign a rank to each level representing the expected difficulty, and assign a rank to the player that evolves depending if he completes the tasks easily or repeats errors and need assistance. We then make use of a normal distribution function FN(R1-R2) to give us a difficulty ratio, and adapt the challenges difficulty and assistance accordingly. This allows us to expect the level of assistance that will be required for a given level and smooth the passage from general to specific assistance and vice-versa.

3.5 PRODUCING EFFECTIVE VISUAL AND AUDITORY ASSETS TO MAXIMIZE COGNITIVE TRAINING

The last aspect of our guidelines concerns the production of assets specifically for AD patients. This is crucial since we must consider the visual and auditory troubles associated the effects of aging, since it represents the main risk factor for AD (Alzheimer's Association, 2001). First, we suggest creating simple scenes as we know that aging can cause difficulties to find objects in visually complex scenes (Ally et al., 2009). We also explain that speed of movements of the cursor or objects in the scenes should be carefully designed. We then suggest using warm and bright colors with simple textures since they are the best seen by elderly persons (Jones and van der Eerden, 2008). We follow with the importance of creating good luminosity but avoid dazzling when creating 3D scenes, and use light to help the patients focus their attention at important objects in the scene. We then propose defining contrasts clearly to improve depth perception, since AD patients often lack the capacity discern figures from backgrounds and will have more trouble perceiving depth when looking at darker areas. One way of doing this is to exaggerate object's outline thickness by using a well-known technique called toon-shading (DeCarlo and Rusinkiewicz, 2007). Finally, we suggest producing multiple assets to make use of different prompts when providing assistance, since specific profiles might not necessarily need assistance in the same context or in the same manner (Lapointe et al., 2013).

3.6 GUIDELINES FOR BUILDING SERIOUS GAMES AIMED AT COGNITIVE TRAINING OF AD PATIENTS

This chapter explained our journey from going through the literature of different fields of study in order to build an effective tool for the cognitive training of AD patients, to the creation of guidelines aimed at helping the research community to build similar tools or to be adapted for developing serious games targeted at other cognitively-impaired patients. The chapter introduced the different guidelines that we published to that end. The following chapter presents the article (Bouchard, Imbeault et al. 2012), that explains the origin of these guidelines and covers each of them in-depth. The result is a comprehensive and easy to use list that covers different aspects that should be considered when developing serious games aimed at AD patients.

CHAPTER 4

DEVELOPING SERIOUS GAMES SPECIFICALLY ADAPTED TO PEOPLE SUFFERING FROM ALZHEIMER

Developing serious games specifically adapted to people suffering from Alzheimer

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Abstract To face new challenges caused by society aging, several researchers have initiated the experimentation of serious games as a re-education platform to help slowing down the decline of people suffering from Alzheimer. In the last few years, academic studies have been conducted and some commercial products (*Nintendo's Brain Age, Big Brain Academy*, etc.) have emerged. Nevertheless, these initiatives suffer from multiple important limitations since they do not really suit perceptual and interaction needs of silver-aged gamers, more specifically people suffering from Alzheimer disease. In an effort to address this important issue, we present in this paper a set of specific guidelines for designing and implementing effective serious games targeting silver-aged and Alzheimer's patients. Our guidelines cover the following aspects: (i) choosing right in-game challenges, (ii) designing appropriate interaction mechanisms for cognitively impaired people, (iii) implementing artificial intelligence for providing adequate assistive prompting and dynamic difficulty adjustments, (iv) producing effective visual and auditory assets to maximize cognitive training. Also, as a case study, we present the prototype of our new serious game for Alzheimer's patients.

Keywords: Serious games, Cognitive training, Alzheimer disease, Adaptation and personalization.

1 Introduction

The video games industry actually constitutes the commercial sector having the fastest worldwide growing rate among all entertainment media. As an example, the revenues realized by games development companies were estimated at approximately 60 billion in 2011 [1] and the projections suggest that they will reach 75 billion in 2015. This rapid growing is a direct consequence of the new market strategy of the game industry, which is to exploit new interaction methods and gaming platforms, such as the *Nintendo Wii*, *Microsoft Kinect*, *Sony EyeToy*, Smart phones, etc., in order to attract a larger community of gamers. This offers new ways of gaming, now enabling non-gamers and the entire family to play together. Recent evolution in these technologies paved the way for what is called serious video games. This new type of digital games specializes in other purposes than just entertaining, such as educating [2], leading societal impact on specific subjects [3], enhance individual user's aptitudes [4] and, more recently, train cognitive faculties of silver-aged gamers [5]. Western countries are actually facing one of worst demographic crisis of their history, leading to an increasing number of people suffering from Alzheimer's disease (AD) [6]. Because of that, a community of researchers [5], [7], [8], [9] has recently initiated the exploration of a new avenue of solutions for cognitive assistance, based on video games. This consists in exploiting video games as a software platform allowing the support of new assistive tools, less expensive and more accessible, that could be used, for instance, as a reeducation tool helping to slow the decline of people suffering from Alzheimer [7]. Several academic studies [5], [8], [9] and commercial products, such as *Nintendo's Brain Age*, *Big Brain Academy* or *Vision Focus*, have emerged. However, most of these serious game initiatives provided only memory challenges or a series of random puzzles to play few minutes per day with the aim of "improving brain performances". These initiatives suffer from multiple important limitations since they do not really suit perceptual and interaction needs of people suffering from AD. For example, they do not provide any form of in-game assistance able to recognize cognitive errors and to support the user accordingly and, they do not provide any form of dynamic difficulty adjustment for matching the user's particular skills and cognitive profile [10], [11]. In the same way, proposed interaction methods do not always exploit the naturalness and multimodal capabilities that current technologies can provide. Moreover, their artistic design (colors, borders, perspectives, etc.) are not best suited for a cognitively-impaired person. Development of serious games for AD patients that can be cognitively effective requires specialized training that will focus on all their four cognitive spheres: memory, planning skills, initiative and perseverance [12]. In an effort to address this important issue, we propose, in this paper, a set of specific guidelines for designing effective serious games targeting silver-aged and Alzheimer's patients. Our multidisciplinary contribution takes several forms. Firstly, we will describe thoroughly and synthetically a set of guidelines covering the following aspects: (i) choosing right in-game challenges, (ii) designing appropriate interaction mechanisms for cognitively impaired people, (iii) implementing artificial intelligence for providing adequate assistive prompting and dynamic difficulty adjustments, (iv) producing effective visual and auditory assets to maximize cognitive training. Secondly, as a case study, we will present the prototype of a serious game developed in our laboratory. Finally, the last part of our contribution concerns our ongoing efforts to validate the proposed guidelines and our prototype. Our multidisciplinary team (computer scientists, neuropsychologists, game designers and engineers) has signed formal collaborations agreements with few local organizations (i.e., local Alzheimer Society, regional rehabilitation center, nursing homes for elders) and health facilities to recruit participants. Therefore, in this last section, we will present the developed experimental protocol.

2 Choosing the right in-game challenges for the patient

Previous researches show that AD patients need specifically adapted challenges [25], and also need help to complete them [16]. Consequently, trainings should dynamically adapt themselves to a given profile in order be fully effective. This aspect may also impact positively the player's engagement since it sustains its interest. In this section, we analyze how the in-game features that should be designed in order to fit the patient's profile.

2.1 Guidelines

Keep trace of the patient's cognitive abilities. One of the important features we were interested in is that the game would be capable of producing an in-game estimation of the patient's cognitive abilities, using the data collected from the different activities. This will allow us to measure the positive impact of the game on the patient's cognitive performance through the training sessions and keep a history of the estimations through time to fully evaluate the game potential. For testing real-life patient's cognitive abilities in smart homes, our lab is using a well-established neuropsychological test called the *Naturalistic Action Test* (NAT) [13]. The test uses adapted activities based on routines actions of everyday life called *Activities of Daily Living* (ADL), in order to assess the patient's errors using predefined score sheets. To answer our need of in-game cognitive evaluation, we decided to develop a game concept based on the activities used in this test, and to integrate the score sheets used for the evaluations in the game, in order to provide a fast estimation of the patient's cognitive abilities during the play sessions.

Determine an appropriate number of steps for the challenges. Each challenges presented in the game should be completed in a correct number of steps. A high enough number of steps would correctly train the cognitive abilities of the patients. However, too much steps could overload them and lower the benefits of the game. As we decided to use an in-game NAT-based test as explained in the previous subsection, we determined that the game levels should be made of 8 to 12 steps, in order to assure they would be compatible with the NAT.

Keep the player in his "flow zone". Keeping the player in is *flow* zone is important. Flow is a well-known concept in the video games community, representing the feeling of complete and energized focus in an activity, with a high level of enjoyment and fulfillment [28]. Maintaining the flow will make the game more fun for elderly gamers, improving their learning experience [14]. It is important to remember that it is more difficult for AD patients to learn new paradigms. Hence, the game must be straightforward and easy to learn in order to avoid confusion or frustration of the player. A good way to achieve this is to recreate a well-known environment and choose challenges that reflect the patient's everyday life, as it will prevent the need of understanding complex mechanisms [15]. Also, placing them in a familiar context will smooth the learning curve and assure a less frustrating, and more enjoyable experience.

2.2 Our choice for the serious game environment

Considering the constraints we defined, and the fact that using ADL would allow the use of a NAT-based test in our game, we decided to base our serious game concept on cooking activities for multiple reasons. First, theses activities respond to the need of recreating a well-known environment for all patients [15]. Secondly, the NAT tests we are using at our lab with real patients are mostly done in a kitchen environment, so the integration in game will be easier since we have plenty of accessible data on the subject. Besides this, the importance of food in everyday life is quite crucial. Thus, not only making the patients prepare meals will train their cognitive faculties, but it will also make them able to repeat such tasks outside the training, i.e., at home [15]. Finally, cooking is a well-established subject in assistive technologies for elders [16], which means information from various researches are easily accessible and will allow us to effectively evaluate the patient through the training process.

3 Designing user interfaces and interaction mechanisms

It is known that physical activities can have benefic effects on brain and cognition [17], [18] as a result, several computer-based rehabilitation systems are based around functional activities. With studies reported in [17] the authors found that exercises effects on cognition were greater for exercice training interventions that exceed 30 min per sessions. Besides many effective results, when implementing these recomendations in traditional therapy approaches, people do often complain about repetive aspects of the exercices and healthcare cost are usually high [19]. In this section we do analyze how interaction aspects of serious games may serve for targetting these aspects.

3.1 Understanding the success of Wii-like games

The arrival of the Wii-like games has promoted a strong integration of video games in centers for elderly. All over the world, it is common to see players who are their late eighties or in their early nineties. To understand this true success, it is necessary to analyze why is the Wii different from others. While interactions with traditional games were essentially based on the couple (keyboard/mouse), with Wii it is rather the natural that prevails. No more need for buttons or arrows in order to move, just do the right gesture and you are done. We refer this as ecological interactions. With such interactions, the learning time is greatly reduced if not absent. Such an aspect is specially important when dealing with elderly. Moreover, because of these realist interactions, the player is more likely to give credit in his task and hence to be engage in it. With more engagement, one can expect more fun and motivations that will let the user perform all the necessary exercises.

Although playing a major role in the Wii success, it is clear that the factors cited above can not, on their own, explain this console’s major success. Besides, one notes that these factors constitute the core of Virtual Reality (VR) technologies which aims to create a virtual environment where the user would felt being in reality. In fact what differentiates these games from VR applications is primarily their affordability in terms of development, maintenance and usage. This explain why games are particularly adapted to rehabilitation. In contrast to VR applications, games are so accessible, nowadays various games are dedicated to home-based rehabilitation.

3.2 Guidelines

Promote ecological interactions. As seen through our analysis, ecological interactions remain a key factor in designing serious games. Effective use of this aspect, should allow at least a significant reduction (maybe elimination) of the learning time. This should lead to greater enthusiasm and can improve engagement of the players in the game. However, it should be noted that interactions must also be thinked in terms of the target group. For example, given that a high proportion of elderly people does suffer from impaired motor skills, interactions based on whole body should a priori be avoided.

Light interface for home-based exercises. One factor that explains the high cost of traditional methods of rehabillitaion is the costs of travelling to rehabilitation centers. Indeed depending on the health condition of the person, it may necessitate several ressources ranging from familly members to an ambulance. When creating a serious game, design choices should be made in a way to offer home-based rehabillitation training. In order to come up with such effective methods, where ecological interactions can be exploited, portable interfaces that does not required any particular skills for configuration should also be considered.

Take advantage of the multimodal aspect. Thanks to developements of VR technologies, now we have at our disposal a set of tools that let us exploit main sensorimotor channels of human when interacting with a machine. For example, voice can be useful for several tasks (to indicate a command) whereas vibro-tactile feedback has proved to be an effective memory aid for users with impaired memory [20]. In this way, exploitation of such modalities can represent a serious alternative for people facing hearing or sight problems. Therefore we strongly advocate the employement of multisensory interactions both as input and output.

4 Producing visual and auditory assets for cognitive training

In order to create a tool adapted to AD patients, it is crucial to consider the effects of aging, as it represents the main risk factor for Alzheimer’s disease [21]. Indeed most AD patients will suffer from hearing and visual troubles associated with aging, as well as sensory troubles caused by Alzheimer. Visual troubles are well-known [22], but the ability of the patients to react different types of visual and auditory prompting for assistance is important as well. Fortunately, researches in smart homes have proven the efficacy of different assistance prompting methods depending on the patient’s cognitive impairments and the level of precision in the assistance we want to provide [11], [23]. This section will discuss the importance of creating assets for different types of prompts and the effects on vision to be taken into account when working with colors and textures, luminosity, and contrast.

4.1 Understanding guidance in smart homes

In the field of smart homes, guidance is the action of taking the result of an activity recognition process and the given profile of a patient, in order build an assistance solution consisting of a sequence of pairs (action / effectors), to help the patient in the completion of his task when needed [23]. The assistance is then done on specific actions using prompts to guide the patient in a progressive manner, by providing general to more specific assistance if the patient did not manage to complete the task. However, types of prompting to be used, depending of the patient's cognitive disorders, and the method to use them is also of great importance [11]. For instance, it can be more effective to use a sound or a verbal prompt before providing assistance as it get the patient's attention. Furthermore, not every prompt types (auditory, pictorial, video, light, etc.) will be effective with a specific patient, depending on his profile [11]. Since our game makes use of assistance, visual and auditory assets should be created for all the types of prompts to be used.

4.2 Guidelines

Create simple scenes and help the player. Before anything else, it is important to avoid unnecessary information in the screen, as we know that aging can cause difficulties to find objects in visually complex scenes [24]. Thus, we must pay attention to create relatively simple scenes in our serious game to avoid the players to be discouraged when not finding the correct object. Furthermore, we add different prompts to help them when they experience difficulties, consistently with the recent advances in the field of smart homes [11], [23], [25]. Finally, it is important to pay attention to the speed of the cursor and object's movement to prevent losing the patient during the play sessions.

Use warm and bright colors with simple textures. According to Jones et al. [22], bright warm colors such as red, orange and yellow are best seen than others by elderly persons. On the other hand, the vision of blue and purple are reduced, and aging also cause dark and pastels colors to be difficultly distinguished. Moreover, aging cause acuity to be reduced, making nearby images to be blurred and details in textures difficult to discriminate. Thus, simple textures should be used for all objects in the game and colors of important visual information should be brighter to get the player's attention and ensure a good visibility.

Create a good luminosity but avoid dazzling the player. When creating a 3D game, colors and textures are not the only thing to consider. To correctly see the scene and the objects, we need to create an environment's luminosity, by choosing what kind of light will be used, their intensity, and how they should be positioned. When working with older people, a good global luminosity is required, but we must avoid dazzling the player from strong light sources, reflections or backlighting. As with bright colors, lightning can be used to get the patient's attention to be directed to an important object or area in the game, as long as it does not disturb his vision. For example, we could generate a gentle spotlight source at the back of the camera to create a cone of light concentrated around a particular object that the player must interact with. If needed, we could also blink this light source to get more of his attention.

Clearly define contrasts and improve depth perception. Older persons have difficulties discerning the limits and borders of objects on a surface, and their perception of depth is reduced. Furthermore, AD patients will often lack the capacity of correctly discerning a figure and the background on which it is drawn and will have more trouble to perceive depth when looking at darker objects or areas (e.g. could perceive a rather black object as a hole in the wall). As a result, the serious game need to present objects with well-defined borders to make it easier for the players to distinct them. This task can be done by choosing different colors for the environment and the objects, as well as different colors for objects that will be in juxtaposition. Furthermore, contrasts and shape perception can be improved by exaggerating object's outline thickness using a shader, such as in a well-known technique in video games called toon-shading [26].

Use different types of prompts when providing assistance. Each patient presents a specific profile and might not necessarily need assistance in the same contexts or even in the same manner [11]. For example, a patient suffering from auditory disorders can benefit from a visual feedback, in comparison with auditory ones, which will not affect him. Therefore, it is important to dispose multiple visual (arrows, animated circle below objects, video of someone doing the task, etc.) and auditory (sounds, voice assistance, etc.) assets, that the game can exploit in order to provide assistances suitable the player's profile. As stated previously, vibrotactile rendering can also contribute to this point.

5 Implementing artificial intelligence for providing adequate assistive prompting and dynamic difficulty adjustments

Recent researches shows that it is more beneficial for AD patients to be helped through completion of a challenge, rather than see the challenge failed and be presented with a new one [27]. Yet, most games on cognitive training such as the popular *Nintendo DS Game*: the *Dr. Kawashima's Brain Training* does not offer either help to the player in the completion of challenges or dynamic adaptation to the player's profile. Therefore, not only these games are not suited to this kind of player, but they does not allow the players to think about their errors and try to correct them, which is an important point in education and re-education [10]. Moreover, we noticed that the tools used in previous research [5], [8], [9] do not make use of modern artificial intelligence technologies such as learning, activity recognition (AR) and guidance (prompting) in order to offer a personalized and more effective experience.

To address the problem of helping a patient, we are interested in using two methods. The first one is well-known in the field of smart homes and consist of, from a user's profile and type of error [23], providing a feedback using technologic effectors to get the patient attention on a specific object, area or task [11], [25]. Then, we make use of a method called *Dynamic difficulty adjustment* (DDA), which consists of calculating the level of challenge experienced by the player in order to adjust the difficulty to match the player's abilities. This section will explain how these methods are implemented in our serious game to make it correctly adapted to AD patients.

5.1 Preliminaries on "Dynamic Difficulty Adjustment" (DDA)

Most video games try to suit all types of players by presenting them a static choice of difficulties to choose from (usually from 3 to 5). The major problem of this approach is that we ask the player to choose a level of challenge, without even having a chance to try the game, and without knowing exactly how this choice will impact on his experience [28]. While this can seems acceptable for experienced gamers, it is certainly not the case for more casual gamers or, in our case, for AD patients, which are usually not familiar with digital form of games [5]. DDA addresses this problem by offering an alternative to mismatches between a player's skill and the game challenges, by modulating in-game systems to respond to a particular player's abilities over the course of a game session [29]. In our game, we decided that this should be reflected by providing more or less precision when assisting a patient.

5.2 Guidelines

Use activity recognition and player's profile to provide assistance. Smart homes and other fields interested in rating human routines often uses Markov processes such as POMDP [23] or HMM [30]. One reason for is that these processes are able to manage uncertainty by evaluating signals (movement captors, RFID, etc.) to make an estimation of the action undertaken by the observed person. In the context of a video game, player's actions can often be directly observed and does not require complex mathematical models. However, since a given task can be completed in different manners, the game should implement a model where transitions can be adjusted, such as a simple MDP. This will allow the model to react correctly after been adjusted by the patient's "usual sequence" for a given task. For certain tasks, it can also be necessary to implement policies to add rules on a given sequence (e.g. coffee must be stirred only after adding milk and sugar).

Keep the player in the flow with DDA. While assistive prompting can help a patient to complete a given task, one of the main goals of a serious game for AD patients is to train their cognitive abilities. To achieve this, it is important to make sure they experience the right level of challenge so they can be fully concentrated and avoid discouragement [5], [28]. Our DDA algorithm is based on the ELO raking system [31], which ranks players depending on their in-game performance [32]. The ELO system makes use of a normal distribution function FN to predict the overcome of a match between two players, depending on their respective relative skill R1 and R2. This prediction is given by FN(R2 - R1), which represents the expectation value of highest ranked player's victory. Since our game is played in solo, the player gets to "compete against the game". Thus, a "skill level" that reflects the difficulty is associated to each level. Then, the result from FN(R2 - R1) gives us a difficulty ratio, which represents the expected level of challenge that will be experienced by the player for the completion of this level. The player’s rank will be adjusted through the game as it will increase if he completes tasks easily, and decrease if he repeats errors and need assistance. This smoothes the passage from general to specific assistance and vice-versa.

6 Prototype, implementation and upcoming experiments

With our case study, we want to design an environment that can help users to train their four cognitive spheres while being fun, interactive, safe, and easy to use. In this game, the player is invited to prepare different meals in a virtual kitchen using the provided ingredients and dishes. Each level presents the player with a predefined meal to prepare, in a smooth learning curve. Thus, the player has simple and clear objectives to complete and the game can assist him whenever he experience difficulties.

Our first prototype implementation was made in Torque Game Builder, a 2D game engine, as shown in figure 1. After some preliminary experimentations guided by neuropsychologists, we rapidly realized that a 3D version of the game could better address the need of patients to be in a familiar environment. Based on guidelines described above, we choose Unity 3D, a professional 3D game engine presenting a free license, as development tool.

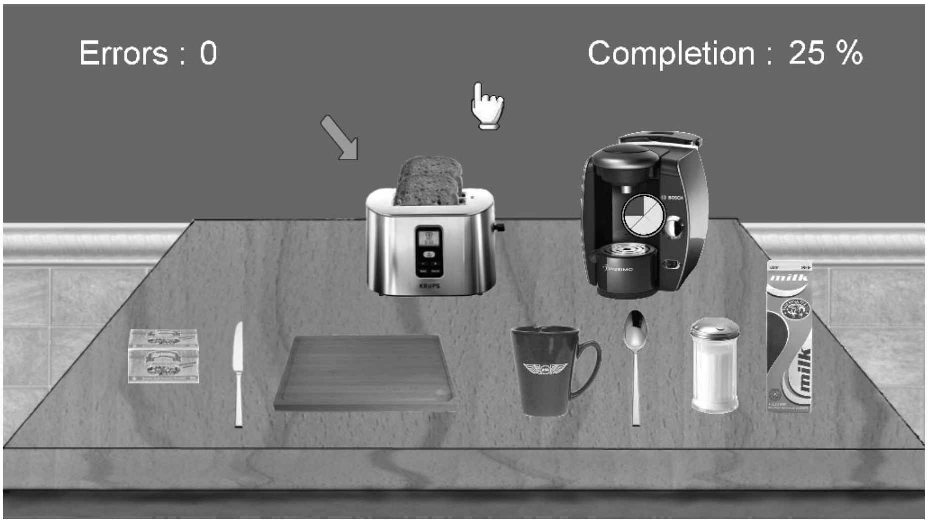

Fig. 1. First prototype in 2D, presenting the player preparing toasts and coffee

The game promotes point-and-click interactions. To challenge planning aspects of the cognitive sphere, a particular attention is paid to the correct order in which the player completes a task. For example, breaking eggs in the frying pan is correct, whereas interacting a cup with the knife results in an error. In the same way, actions in the game levels need to be completed in a logic sequence. For instance, coffee and milk must be added together before any stirring can occurs. On the other hand, some actions can take time before requiring the player's attention such as frying eggs. In that case, a timer would appear to indicate the remaining time before completion. All these simple mechanisms have been designed in order to make the game easy to learn and play. The serious game presented in this paper is mainly working and is now in a polish phase concerning mainly the creation of visual and auditory materials. In fact, we are currently working with professional artists for 3D models, textures and user interface development. In the meantime, formal agreements between our lab and ours partners are already established. We are hence in position for preparing our upcoming experimentations and obtain the collaboration of AD patients. Two main partners can be count. The *CSSS Cléphas-Claveau of Ville LaBaie*, a regional rehabilitation center which welcomes many AD patients and is in charge of diagnosing all cognitively impaired patients in our region (pop. 150K), and the *Cooperative de solidarité en aide domestique*, a daycare center for Alzheimer patients.

Our experimental protocol will be conducted in three separate phases: experimenting with trial data sets, experimenting with Alzheimer's patients and analysis of the experimental results. The first phase has already begun; it also serves for debugging the proposed game. Once completed, the game will be tested with a group of about 20 AD patients for duration of 3 to 4 weeks. Those tests sessions will be observed and evaluated by a team of multidisciplinary experts, and will be filmed and conserved in our database for future experiments. Finally, the data from the experiments will be analyzed in order to measure the power of our serious video game in cognitive training. This phase will consist of comparing the gathered data from the game to real NAT results obtained for the same patients for testing the validity of our in-game data, and comparing the evaluations made before and after the training period to measure the positive impact of the serious game. Lastly, we want to test whether the results will be sustained after the training or not, by comparing the results obtained at the end of the training period and the ones obtained 3 weeks later. This will give us information on the possibility to train patients in a long-term vision.

Conclusion

This paper addressed the exploitation of serious games as a training platform for patients suffering from Alzheimer diseases. To be effective, it appears that such games should meet different criteria. Here we have propose a guideline that structures these requirements under four points. This guideline covers the choice of the in-game challenge, the design of the interactions, the implementation of the artificial intelligence and ends with the production of visual and auditory helps. As a case study, we have presented a game where users are invited to prepare meals. With our upcoming experimentations with patients suffering Alzheimer, this game will serve for the validation of our guideline.

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CHAPTER 5

CONCLUSION

The video game industry has been rapidly growing in the past decades and its potential has interested the scientific community in various different fields. The understanding of the psychology of fun and the concept of flow in games paved the way for the development of games which are built for a primary purpose than entertaining, called *Serious Games*. These games have gained interest in fields such as promoting healthy behavior in children (Majumdar et al., 2013), supporting rehabilitation in disabled patients (Prange et al., 2015), training medical personnel (Graafland et al., 2012, Graafland et al. 2014), increasing social awareness (Rebolledo-Mendez et al., 2009) and using Game-Based Learning as an education tool (Egenfeldt-Nielsen et al., 2011).

In the past years, research on neurodegenerative disease such as Alzheimer's disease (AD) had significant increase due to the urgency of the aging population. Notable areas of research to address this issue include researches in Smart Homes to increase the quality of life and autonomy of cognitively-impaired patients. In this field, researchers have been interested in using technology deployed throughout the living environment (sensors, RFID, effectors, etc.) to help its resident by providing assistance in daily tasks (Bouchard et al., 2007, Mihailidis et al., 2007). Indeed, studies shows that it is more beneficial for AD to be helped through the completion of tasks, rather than simply see these tasks fail (Pigot et al. 2003). Research in this field also shows that assistance must be adapted depending on the patient's profile and nature of task (Lapointe et al. 2013). On the other hand, some studies have also been exploring different methods and the benefits of cognitive training for the elders. To that end, researchers have been using tools such as close-to-reality simulations (Hofmann et al., 2003) or commercial games (Nacke et al., 2009) in order to train the cognitive abilities of AD patients. However, none of them has been at the same time presenting challenges focused on cognitive spheres that should be trained for AD patients (Baum and Edwards, 1993), and implementing state of the art Artificial Intelligence (AI) in order to provide specifically adapted assistance through the completion of different tasks (Lapointe et al. 2013).

The objective of the first paper (Imbeault et al., 2011), presented in chapter 2, was to exploit the potential of Serious Games and make use various researches in the field of assistance in Smart Homes and cognitive training, in order to build a tool specifically adapted for the cognitive training of AD patients. In that sense, the paper presents an in-depth description of our Serious Game prototype we developed specifically for the cognitive training of AD patients. We then explain our choice of using a Serious Game for that matter and describe the reasons behind design choices of the game settings and mechanics. We also detail our different systems such as our Dynamic Difficulty Adjustment (DDA) algorithm, the player's profile adaptation for adapted assistance during challenges, and the in-game cognitive evaluation. Finally, we expose our experimental protocol and our ongoing efforts to conduct experimentations.

The objective of the second paper (Bouchard, Imbeault et al. 2012), presented in chapter 4, was to create guidelines for the development of Serious Games specifically adapted for the cognitive assistance of AD patients. The idea behind those guidelines was to create a source of information easily usable by the research community to either create similar tools targeted at AD patients, or to create tools targeting other types of cognitively-impaired patients by adapting those guidelines. The paper was organized to provide information in four different aspects: (i) choosing right in-game challenges, (ii) designing appropriate interaction mechanisms for cognitively impaired people, (iii) implementing artificial intelligence for providing adequate assistive prompting and dynamic difficulty adjustment, (iv) producing effective visual and auditory assets to maximize cognitive training.

In a larger perspective, we think our work will help further research on the development and usage of Serious Games in the field of cognitive training. We realize that this kind of game has proven efficiency in many fields and could have high potential in the re-education of mentally impaired patients, such as patients suffering from AD. Our research is part of a wider project conducted by the LIARA laboratory of the University of Quebec at Chicoutimi, that specialize in Smart Homes, activity recognition and assistance for AD patients. We hope that this research will generate enthusiasm in the scientific community for the usage of games for cognitive training.

Finally, I would love to conclude with a personal note on my experience. The journey from my initiation to the complex and fascinating world of scientific research to writing down those last lines has been excessively rich and rewarding. Even with modest contributions to the scientific community, the acceptation of our presented papers by peers is a token of acknowledgement for our hard work, which is of great value. Through this adventure, I have learned a lot and had the chance to work with a team of highly talented people working in different fields but driven by the same goal: to help patients suffering from AD. I am grateful for the opportunities I have been given and the generosity of the team working at the LIARA. I hope our contributions will help further research on the development of efficient tools that can be used to help AD patients.

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