

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. These 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 do 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 shows 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 II introduces the relevant related works in serious video games and cognitive training in Alzheimer's disease. Section III brings forward our theoretical contribution, including the conceptual model of the game. Section IV describes the implementation realized to test our concept and presents

technical aspects of the game. Section V exposes our ongoing efforts to conduct experimentations and describes our experimental protocol to be used. Finally, Section VI 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 losing 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 Rebollo-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.

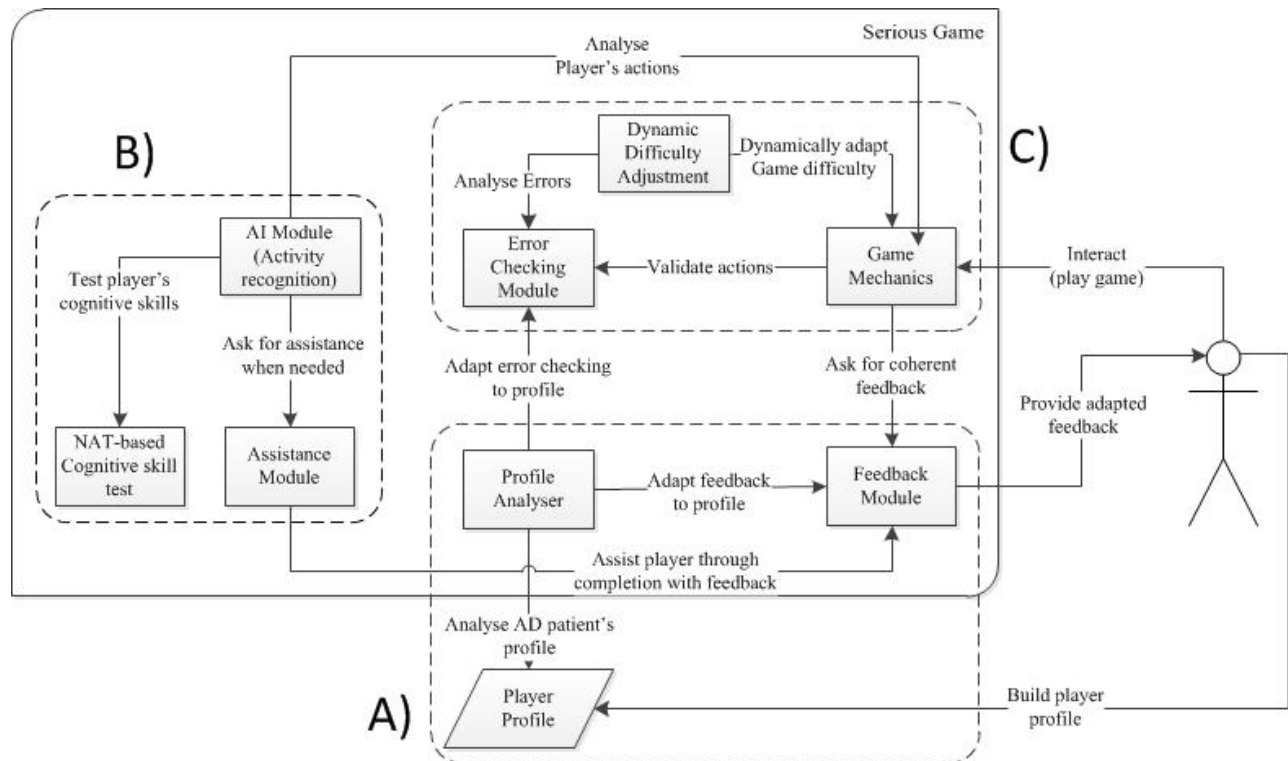
B. Game software architecture

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 the subsection III, A. 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, these 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 the portion 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 part 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,



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 the subsection II. B. 3.

2) *Activity recognition for dynamic assistance and cognitive abilities estimation*: The portion 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 analysis 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 portion 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 uses a library of plans created using description logic [22] to match his guidance to the patient's strategy.

The last part of portion B) of our game architecture is the *NAT-Based Cognitive Skill Test*. This last module uses the results from the activity recognition module to fill the score sheets integrated in the game, explained in the subsection III, A, 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)*: The portion 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. Portion 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 Since our game is only played in solo mode, 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. 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.

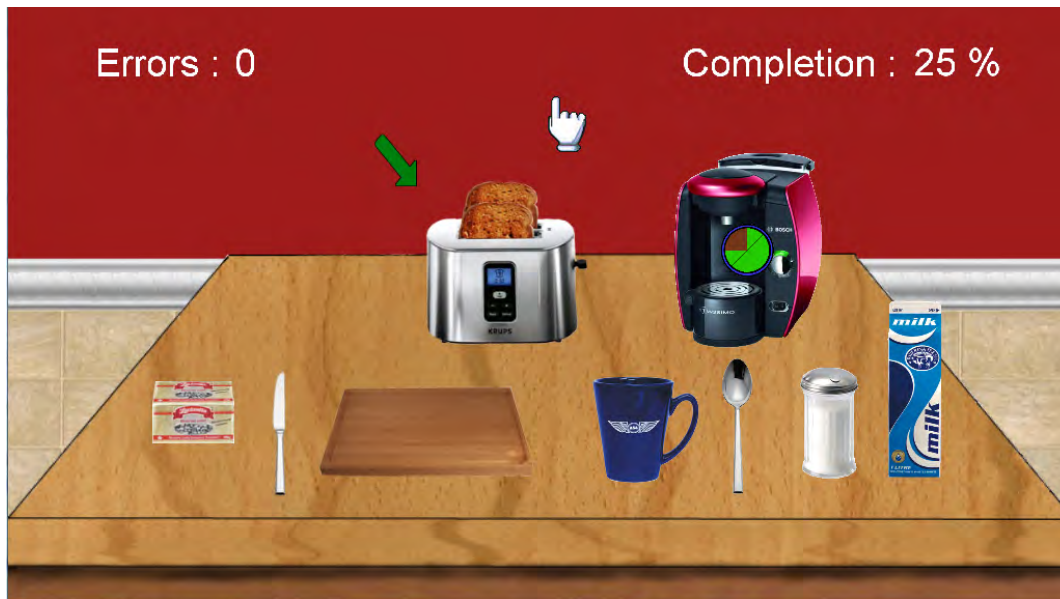


Figure 3. Our serious game prototype for AD patient's cognitive training.

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 IV 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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