	SEVENTH FRAMEWORK PROGRAMME Information and Communication Technologies
Grant agreement number	FP7-611650
Project acronym	DOREMI
Project Title:	Decrease of cOgnitive decline, malnutrRtion and sedEntariness by elderly empowerment in lifestyle Management and social Inclusion

Deliverable Number:	D5.5
Title of Deliverable:	Cognitive Games
WP related to the Deliverable:	WP5
Dissemination Level: (PU/PP/RE/CO)*:	PU
Nature of the Deliverable: (R/P/D/O):**	P
Contractual Date of Delivery to the CEC:	31/10/2015
Actual Date of Delivery to the CEC:	30/11/2015

WP responsible for the Deliverable:	IMA
Author(s):	Antonio Ascolese (IMA), Daniele Musian (SI4LIFE)
Contributor(s):	Vito Nitti, Luca Trapasso (IMA)
Reviewer(s):	Jennie Hancox (DMU)

*Dissemination Level:
PU=Public
PP=Restricted to other program participants (including Commission Services)
RE=Restricted to a group specified by the consortium (including Commission Services).
CO=Confidential, only for members of the consortium (including Commission Services).

**Nature of Deliverables:
R=Report
P=Prototype
D=Demonstrator
O=Other

Abstract

Deliverable 5.5 ‘Cognitive games’ provides a description of the Cognitive Area, within the gamified environment (presented in D5.2), which aims to motivate users to perform cognitive brain training exercises.

The main aim of D5.5 is to outline the integrated prototype of the whole application and describe in more detail the process, functionalities and clinical aspects of the cognitive games. Technical aspects are also presented to show how the DOREMI application communicates with the game server and with the KIOLA server.

D5.3, 5.4 and 5.5 can be seen as three ‘twin documents’, intentionally following the same structure. These three documents describe the content of the DOREMI application, the integrated working prototype containing the Exercise Area (D5.3), the Social Area (D5.4) and the Cognitive area (D5.5).

Keywords

Cognitive games, cognitive impairment, memory, attention, praxis, calculation, gamified environment

LIST OF BENEFICIARIES

No	Participant Organisation name	Short name	Country	Project Entry month	Project exit month
7	IMAGINARY SRL	IMA	Italy	1	36
1	CONSIGLIO NAZIONALE DELLE RICERCHE	CNR	Italy	1	36
5	FUNDACIO PER A LA UNIVERSITAT OBERTA DE CATALUNYA	UOC	Spain	1	36
8	DE MONTFORT UNIVERSITY	DMU	United Kingdom	1	36
10	SCIENZA E IMPRESA INSIEME PER MIGLIORARE LA QUALITA' DELLA VITA SCRL	SI4LIFE	Italy	1	36

VERSION HISTORY

Version	Primary Author	Version Description	Date Completed
0.1	Antonio Ascolese	Initial version	01/09/2015
0.2	Antonio Ascolese	Wireframe description	30/09/2015
0.3	Vito Nitti	Integration of the technical description	29/10/2015
0.4	Antonio Ascolese	Minor changes	30/10/2015
0.5	Daniele Musian	Clinical implications	03/11/2015
0.6	Antonio Ascolese	Minor changes	04/11/2015
0.7	Antonio Ascolese, Daniele Musian	Changes after internal review	09/11/2015
0.8	Antonio Ascolese	Updated with paragraph 4	30/11/2015

Table of contents

List of figures

List of tables

1. ABBREVIATIONS

API - Application Programming Interface
JSON - JavaScript Object Notation
OECD – Organisation for Economic Co-operation and Development
MCI –Mild Cognitive Impairment
AD –Alzheimer Disease
STM – Short Term Memory

2. EXECUTIVE SUMMARY

The purpose of WP5 within the DOREMI project was to design and develop the gamified virtual environment. The virtual environment represents the main access point for the DOREMI end users. Using the DOREMI application on their tablet, users can engage in the virtual environment where different activities, related to the life protocols fine-tuned in WP2, are presented (as in D5.2). The game environment, considering both the clinical requirements and the user motivation and engagement, contains three different areas, specific for each clinical protocol: the Cognitive Area (presented in D5.5), the Exercise area (presented in D5.3) and the Social Area (presented in D5.4). As these three areas are already integrated in a unique app, as in the final version that will be used by the DOREMI end users, an integrated prototype is presented. This working and usable prototype presents the game environment with the whole functionalities studied, designed and developed thanks to user-centered design (D5.2). From this virtual gamified environment it is possible to access the three areas where the clinical protocols are presented.

The unique prototype (the same for D5.3, D5.4 and D5.5) goes with three different 'twin documents' that help to explain how the prototype works and how it was designed and developed. For all these reasons it was decided to maintain the same structures for the three documents, to cover the same explanation needs. The structure of the three deliverables is:

Section 4 presents one (or more, if necessary) wireframe(s) of the specific area presented in the document. A wireframe is a design document. It is prepared based on: the product guidelines, information collected from users during previous phases of the project, new ideas tested during the DOREMI project, and information on specific issues that arose during the design of the application. These wireframes present the connections between the different functions or sub-sections of the different areas. For this reason, a lot of pictures are presented here. Pictures can represent the application in previous versions, but the main aim is to present the functionalities and the way the application works.

Section 5 presents the clinical aspects of the specific area. All the functions and the elements of the Cognitive Area, the Exercise Area and the Social Area, are designed and developed starting from the clinical protocols fine-tuned and presented in WP2 and every decision was taken in agreement with the clinical partner of the project. Clinical aspects were always considered the most important ones in all the phases of design and development.

Finally, section 6 tries to summarise all the technical decisions of the specific section. In particular, all the aspects involved in the communication process with the Game Server and the KIOLA system are described. This section is divided into two sub-sections; the first one is the common description, which is the same for each of the three deliverables, while the second one is a description of the specific content of each deliverable.

3. INTRODUCTION

In the frame of the DOREMI project, the main objective of WP5 'Development of social and gamified environment' was to design and develop a prototype of a gamified environment to engage users and motivate them to complete the proposed daily activities according to the 'Active Ageing' lifestyle protocols prepared in WP2. This environment will be the access point for users to different sets of cognitive games, social networking, exergames and gamified activities. D5.1 has already described the gamification strategy that has been implemented in the gamified environment (D5.2).

In this context, D5.5 addresses the objective to present a prototype of the Cognitive Area. The Cognitive Area is the section of the DOREMI where clinical protocol about cognitive training is presented to the users. This section, as with the other two clinical main sections, was designed and developed following user-centered design process (see D5.1 and D5.2). This approach was utilized to ensure that the DOREMI application is usable and has value to the target group. At the same time, both the design and the development activities were based on the clinical deliverables (D2.1, D2.2 and D2.3) and the lifestyle protocols suggested by clinical partners of the consortium. Finally, all the international guidelines regarding the development of applications for this specific target group were taken into account (as presented in D5.1).

The three clinical sections are already integrated in the gamified environment (this took place during month 24 of the project), and for this reason they are presented as a unique prototype, as it will be in the final version for end users. The three sections are strictly interdependent of each other and are also dependent on the whole functioning of the gamified environment.

4. UPDATE OF GAME-BASED ACTIVE AGEING ENVIRONMENT

D5.2 (Game-based active ageing environment), according to the DOREMI Document of Work, was delivered in M14, when activities regarding the design and development of the gamified environment should have been closed. Nevertheless, as also explained in D5.2, according to the methodological approach that was chosen to design the game-based environment (User Centered Design) and according to the key role of the environment in WP5, the task couldn't be considered definitively closed in M14. For this reason, D5.2 presents the gamified prototype in a temporary version. After M14 user centered design activities went on, collecting feedback with users, at the same time of the feedback collection about the main areas of the application, in UK and in Italy, with different and updated versions of the prototype. For this methodological reason, the design of the game environment continued in parallel with T5.3, T5.4 and T5.5, until M24. Furthermore, to obtain a well-integrated and working application (both from a look&feel and a usability perspective), it was necessary to design and develop the environment at the same time of the three main areas of the application.

The final version of the game-based active ageing environment is presented and ready for a trial in the prototype delivered for D5.3, D5.4 and D5.5. However, in this document a brief walk-through of this final version is shown.

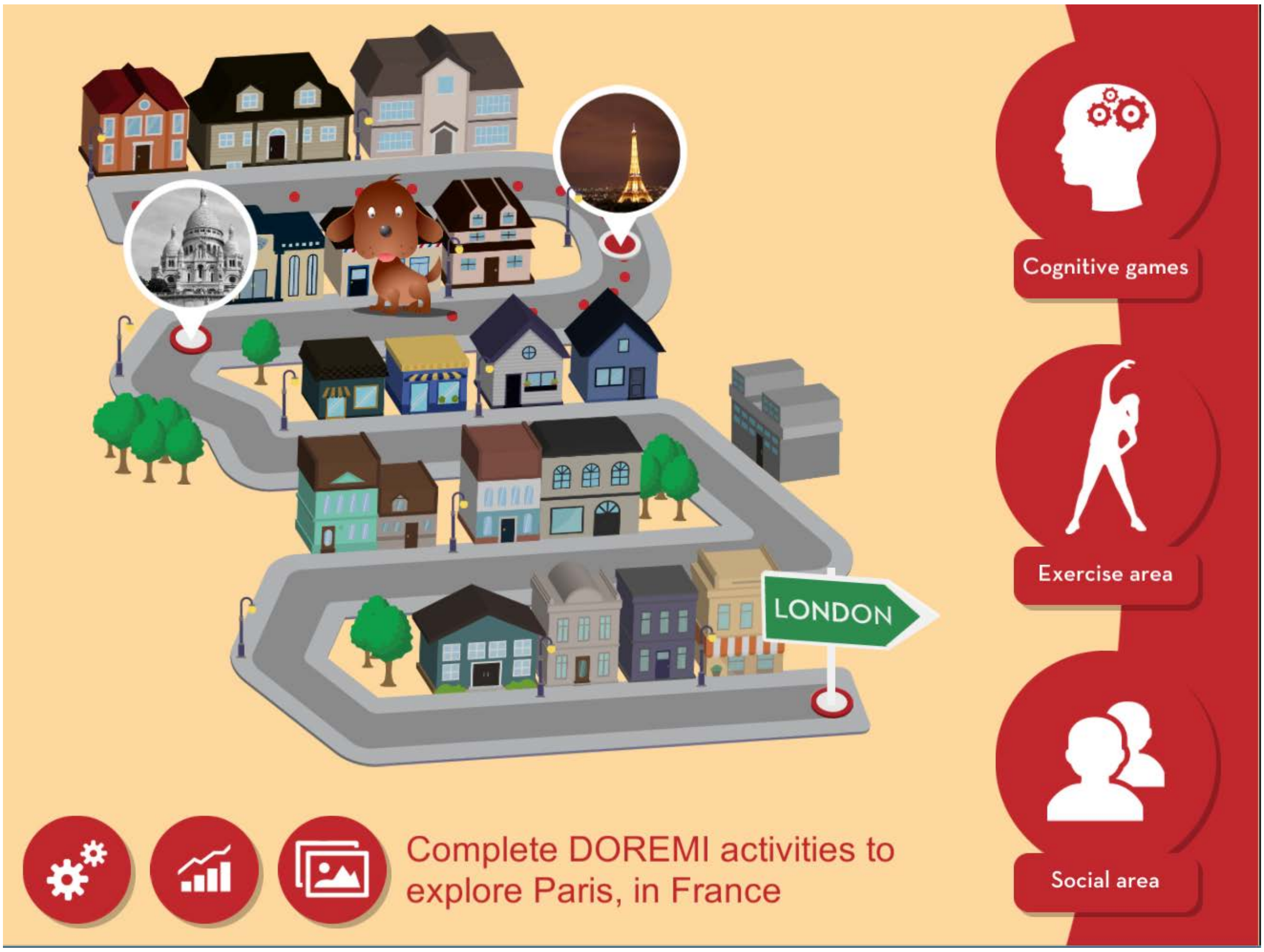

Figure 1 - The main page of the DOREMI game-based active ageing environment.

As designed for the first mock up, in the gamified environment each user has to walk the dog around a path, based upon aggregate scores from all 'clinical' areas and 'real' activities. Each path represents a European city. For each of these cities, there are five different milestones, used to engage the users and motivate them to continue their activities (based on the life style protocols). These milestones represent four different important monuments, famous in that city. The last milestone is represented by the sign of the next city that users can visit (London in Figure 1). Completing all the suggested activities (cognitive games, physical exercises, social interactions and nutritional diary), users can reach a milestone every day. Of course they can also need more time to reach milestones.

On the path, users can see only the next milestone (Sacre Coeur in Figure 1) in a black and white picture; all the milestones already reached (Eiffel Tower in Figure 1) in coloured pictures. All the unlocked achievements are collected and can be seen in a dedicate area, the 'Achievement section'.

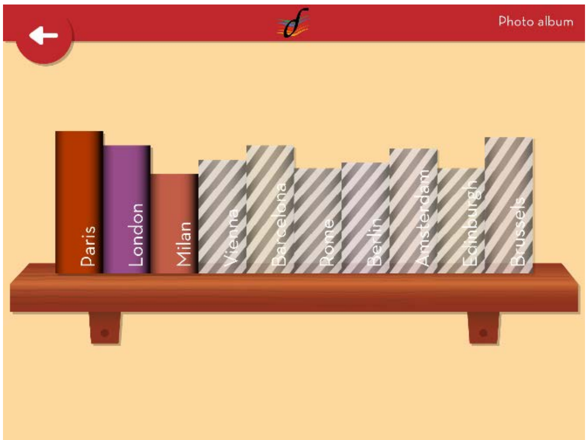

Figure 2 - The Achievement section.

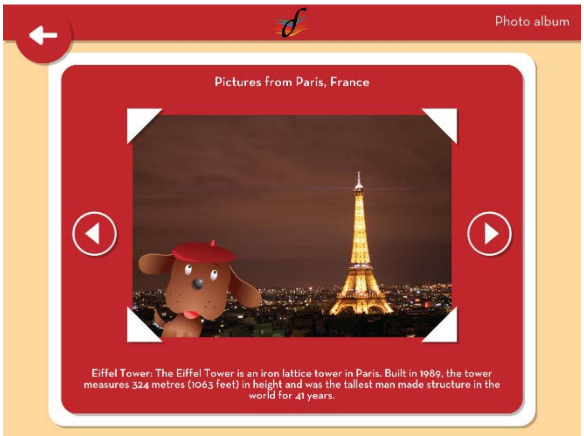

Figure 3 - An example of achievement: A picture from Paris in the photo album.

In the achievement section, a photo album for each of the cities that can be 'virtually visited' through the DOREMI application is shown, distinguishing the already unlocked ones (Paris, London and Milan in Figure 2) and the locked ones. Touching each of the unlocked photo album users can open the book and see all the collected achievements (Figure 3), with a brief description of the monument.

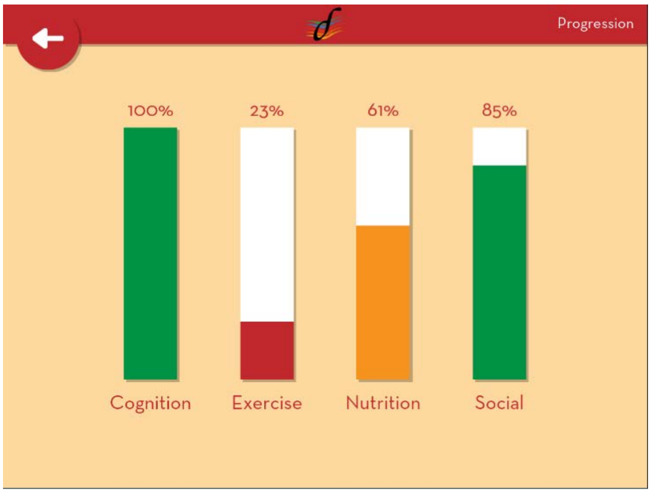

Figure 4 - The progression area

Furthermore, in the ‘progress area’ (Figure 4), users can see how close they are to reaching the next level and traveling to a new city. The bars represent their progress in cognition, exercise, nutrition and social activities. When all four bars reach 100% they will progress to the next level and be able to explore the next city. Each time they achieve a new level the bars will reset to 0%. In this way users can easily understand witch kind of activity they need to train more or, in other words, which kind of health behaviours they should increase.

After each day, all the data collected by the DOREMI application and all the other sensors used in the project are sent to the DOREMI server, where the reasoner merge everything and through specific calculation (implemented within WP4 activities) gives back to the application data that are used to move the dog along the path and update the progress area.

5. DESCRIPTION OF THE COGNITIVE AREA

In this section the wireframes of the Cognitive Area are presented. A wireframe is a design document, prepared before the development of the application and, for this reason, not always correspondent to the final version of the prototype. These wireframes present the connections between the different function or sub-sections of the different areas. The main aim of this representation of the Cognitive Area is to present all the functionalities and the way everything works in the application.

The whole Cognitive Area is shown in the biggest picture with arrows (Figure 5). The other images (Figure 6,7,8,9,10,11,12,13,14) represent a more detailed view of it, where numbers indicate connections between different pages.

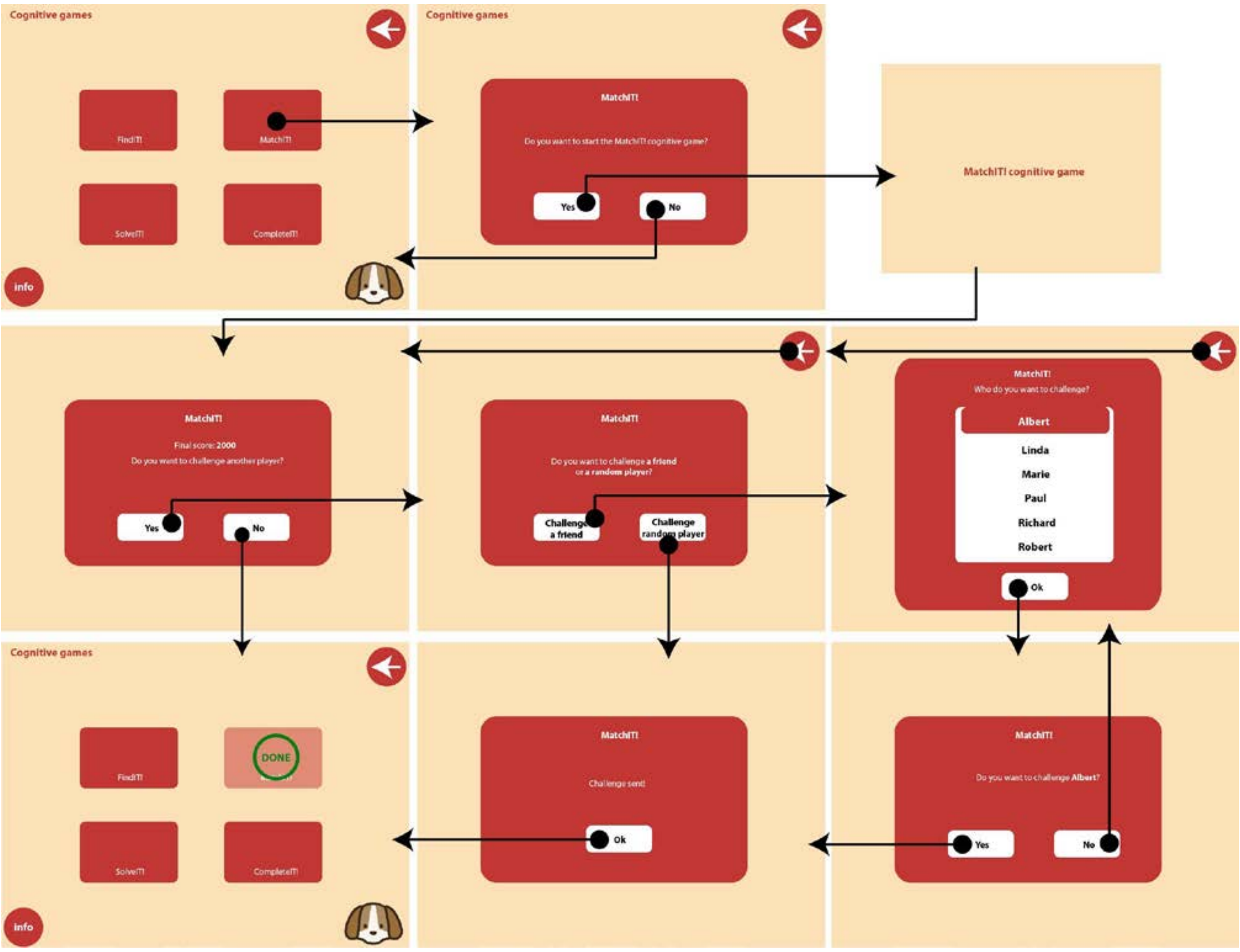

Figure 5 - The complete wireframe of the Cognitive Area.

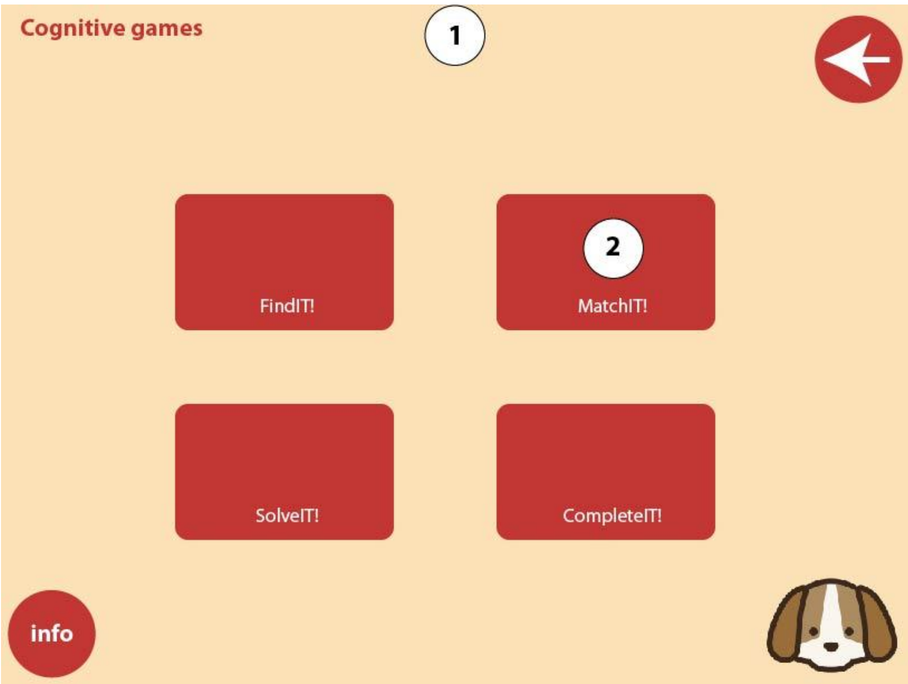

Figure 6 - The player can choose which game to play.

Figure 7 – After the game selection, a confirmation pop up opens.

Figure 8 - The player plays one of the games.

Figure 9 - At the end of the game, the player gets a score and can choose to challenge antoher player.

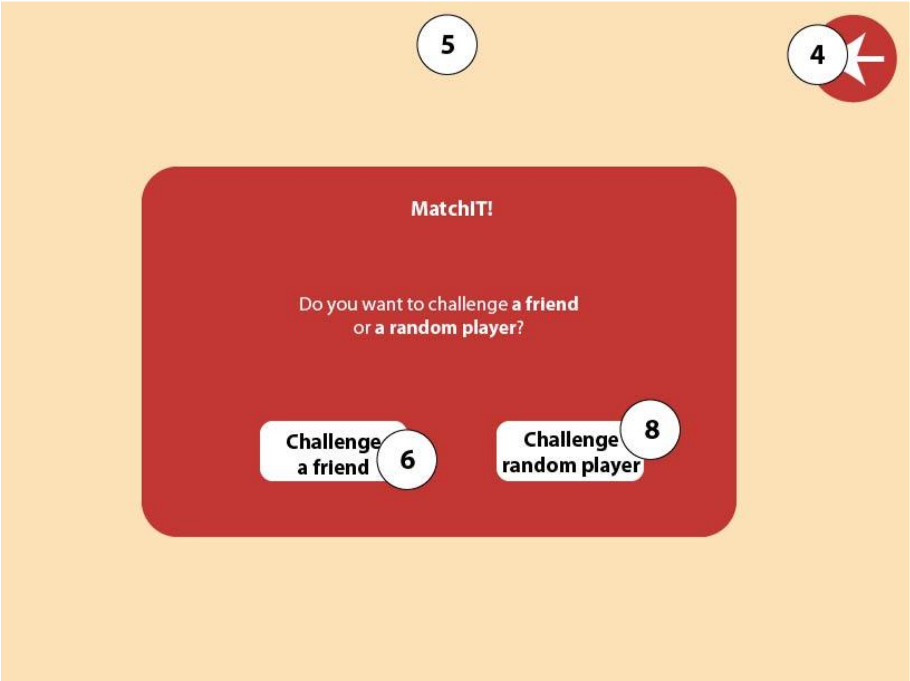

Figure 10 - The player can choose to challange a friend or an unknow user. In this second case the system will use a random system to select the second player.

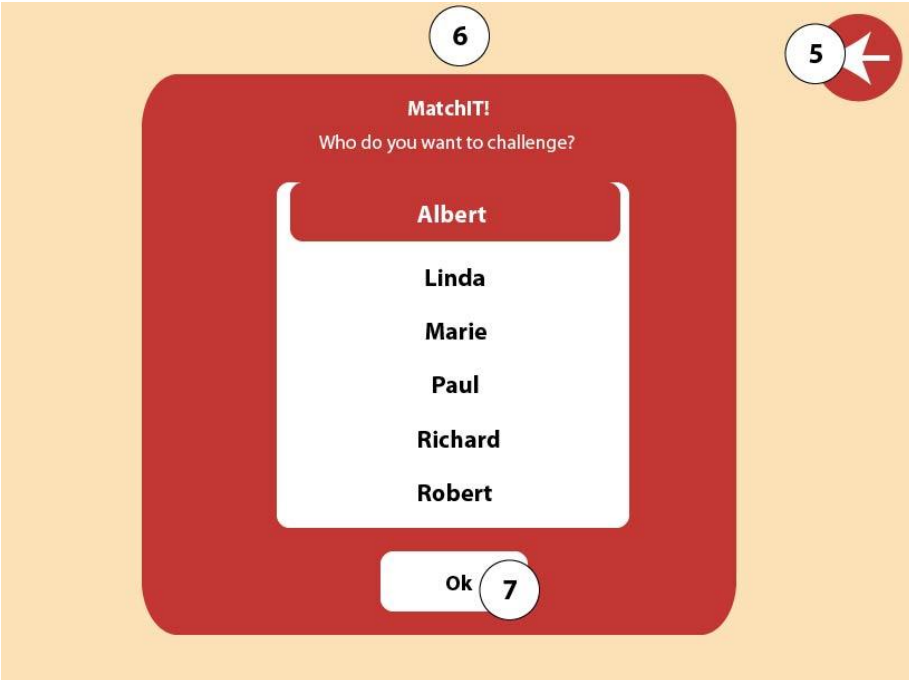

Figure 11 - The player can select which friend to challenge from a scrollable list. In this list all the users involved in other challenges appear.

Figure 12 - After the friend selection, a confirmation pop up opens.

Figure 13 - A popup shows confirmation of challenge forwarding.

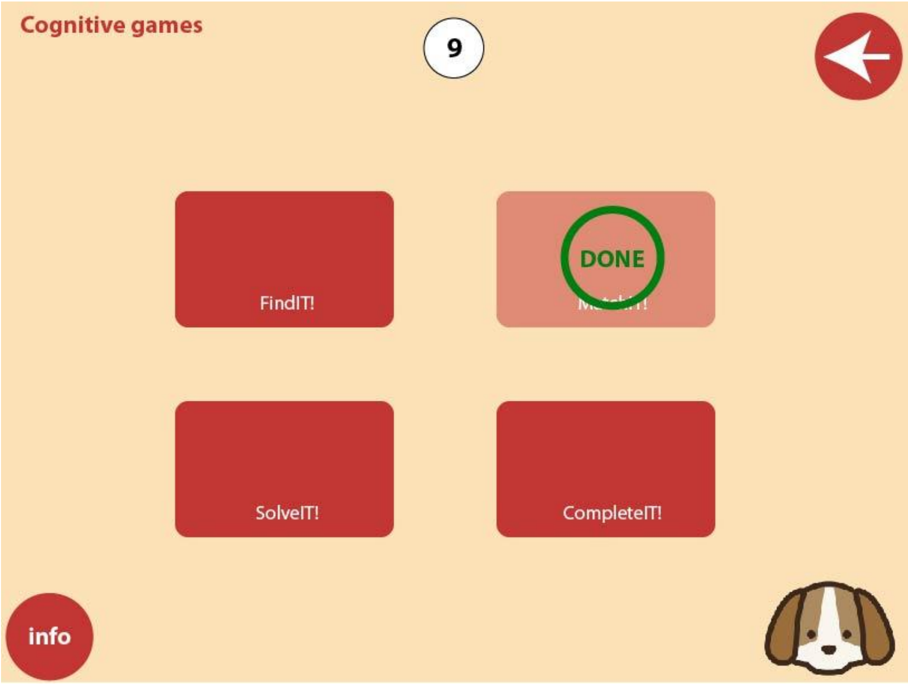

Figure 14 - After completing a game, the menu will be updated.

4.1. Stage status

Figure 15 - Every game includes three different difficulty levels and each level is composed of five different stages. During each game, always visible on the left side of the screen, the status of progression is shown, divided per level: the red points represent

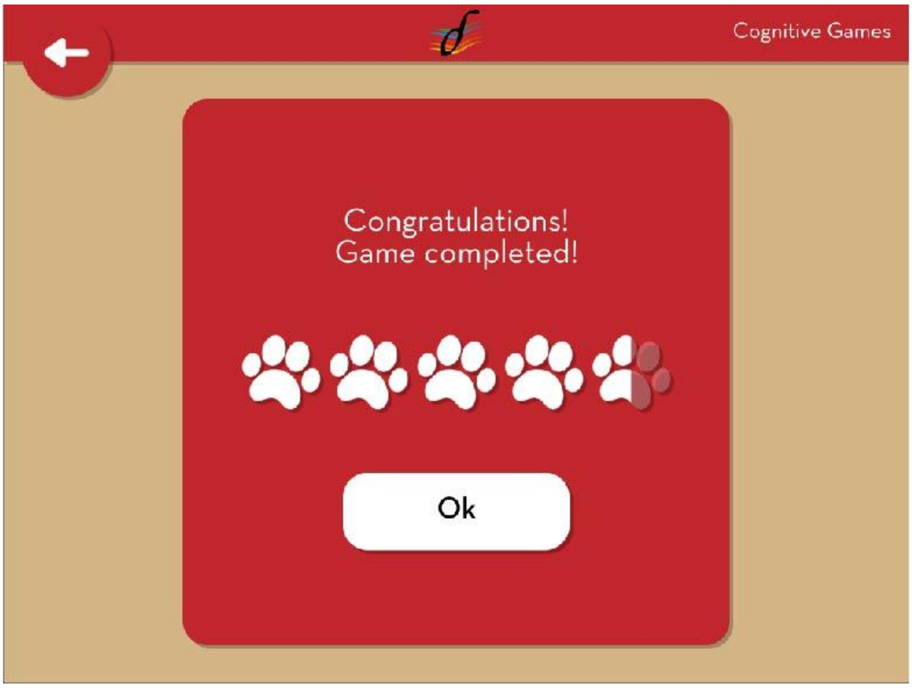

Figure 16 - At the end of the third level (after fifteen stages), the player gets a score, represented by the coloured paws, based on the player's precision, speed and errors made.

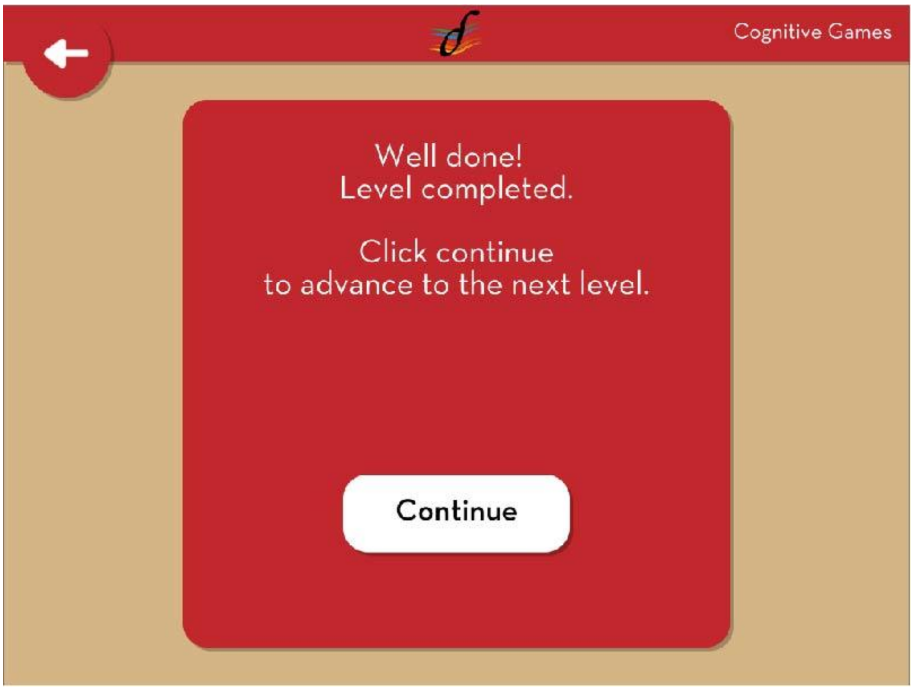

Figure 17 - At the end of every level (after five stages) a popup will congratulate with the player.

Figure 18 - In any moment during the play it is possible to pause the game and decide to drop out of it, resume it, or restart the current stage.

4.2. Find It! Game

Figure 19 - At the start of the game, instructions are presented to the player, explaining the objective of the game and how to play it.

Figure 20 -To avoid the player starting the game without reading the instructions, there is a countdown before the 'start' button becomes active.

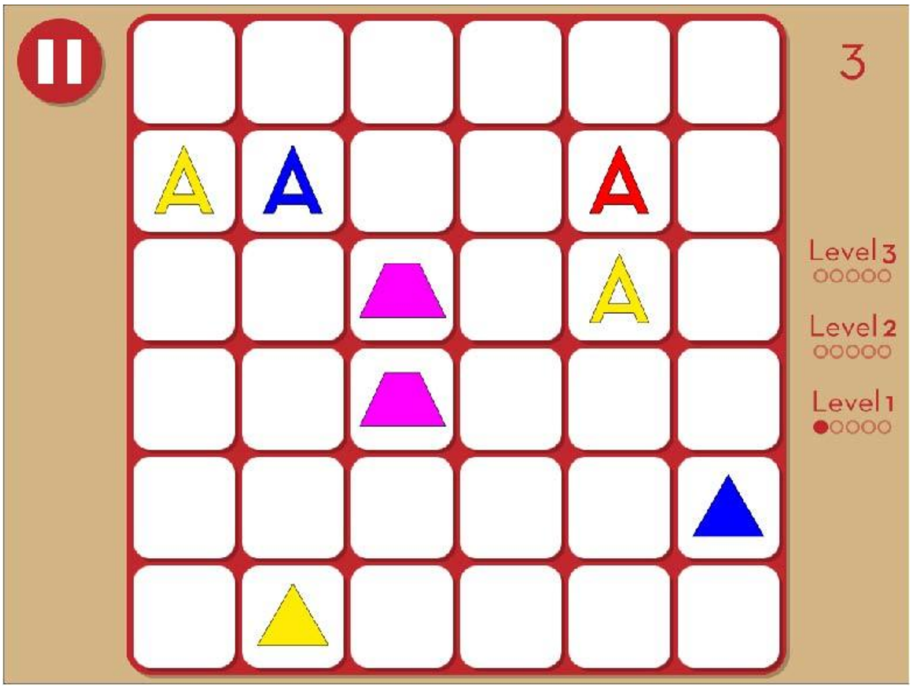

Figure 21 - On the screen, there is a board with various squares, some empty, some with the objectives and some with distractors. Every time a player touches a square feedback (visual, auditory and haptic) is given as to whether the touch is right or wrong.

4.2. Match it! Game

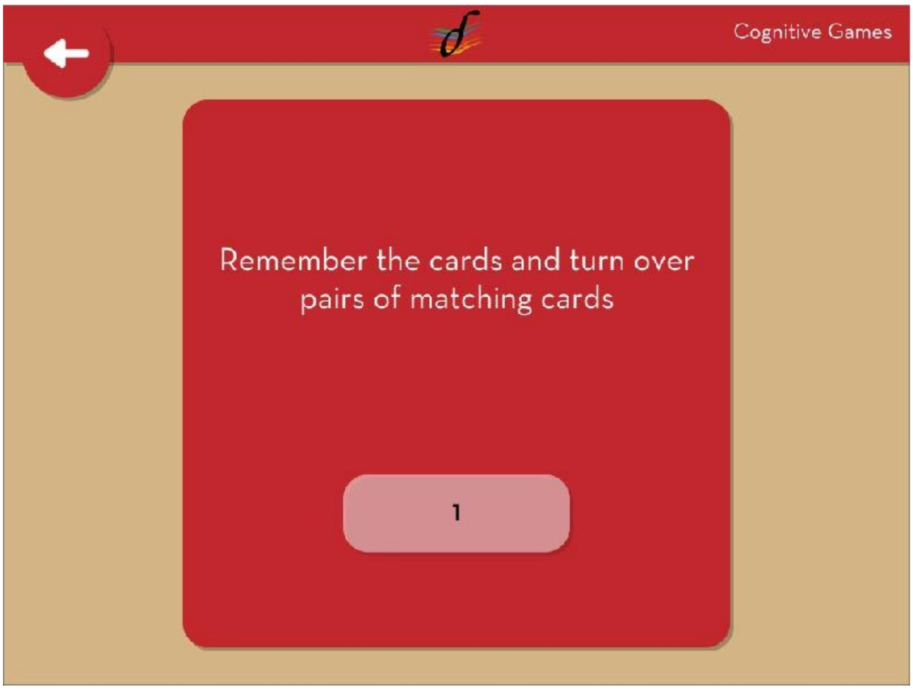

Figure 22 - At the start of the game, instructions are presented to the player, explaining the objective of the game and how to play it.

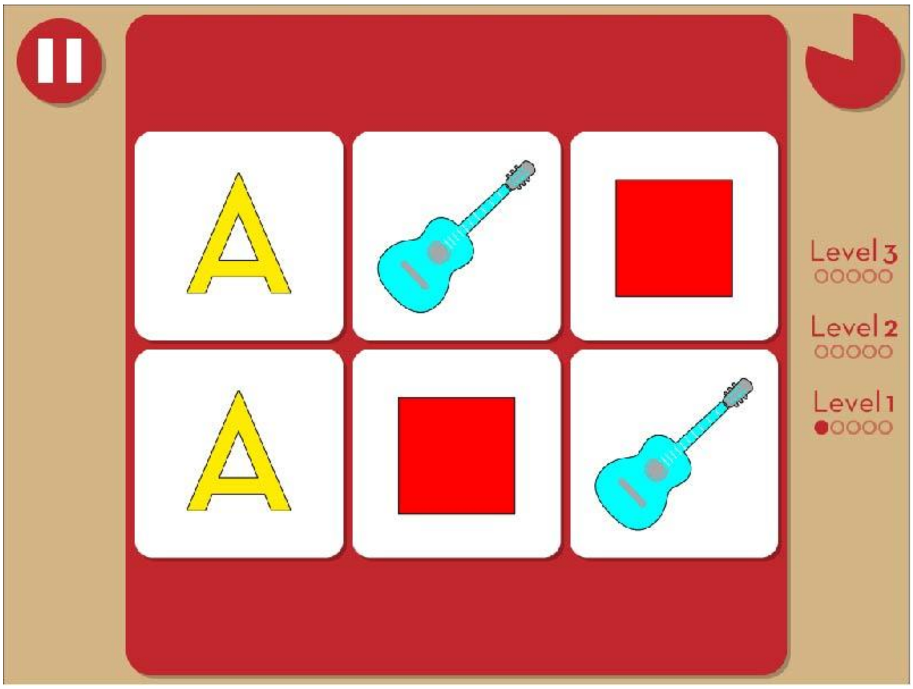

Figure 23 - At the start of every level, all cards are shown to the player for a limited time (exposition time). The time is shown though an animation in the upper right corner of the screen.

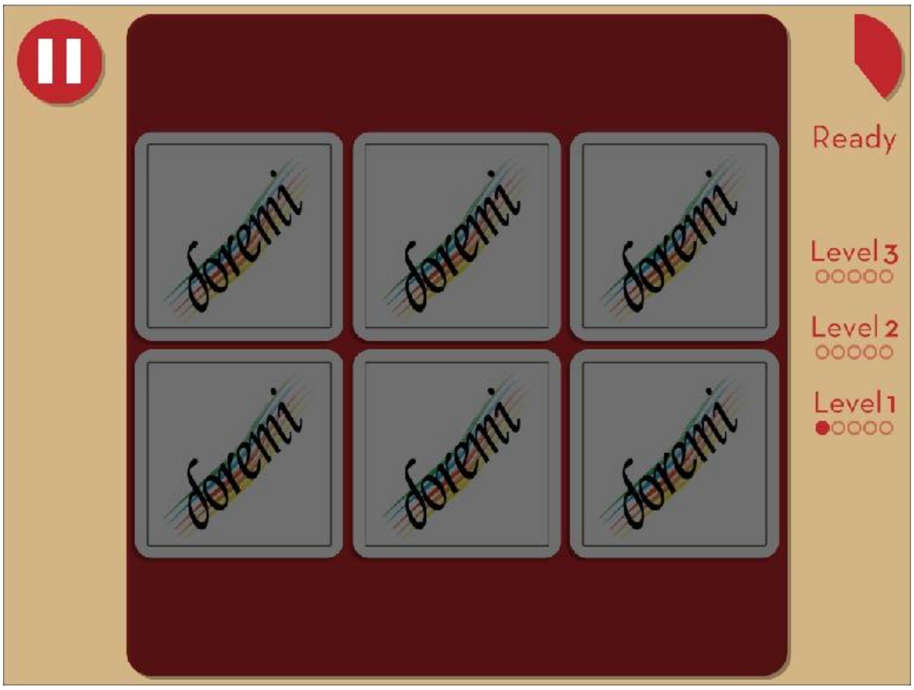

Figure 24 - After the exposition time, all cards are turned over and a new timer starts (retention time). The time is shown through an animation in the upper right corner of the screen.

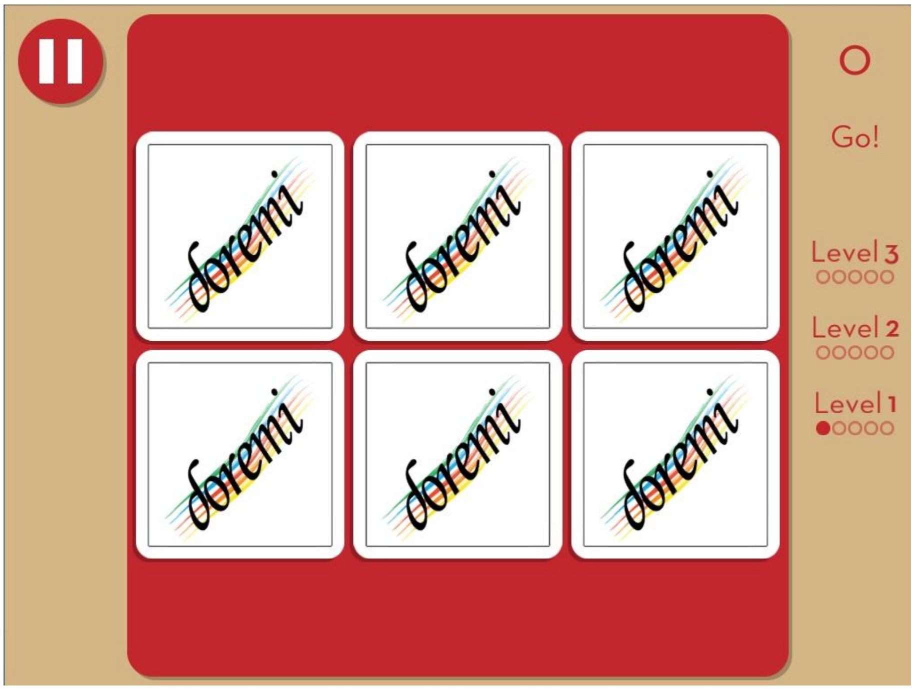

Figure 25 - After the retention time, the player can start to turn the cards over and try to match all the pairs.

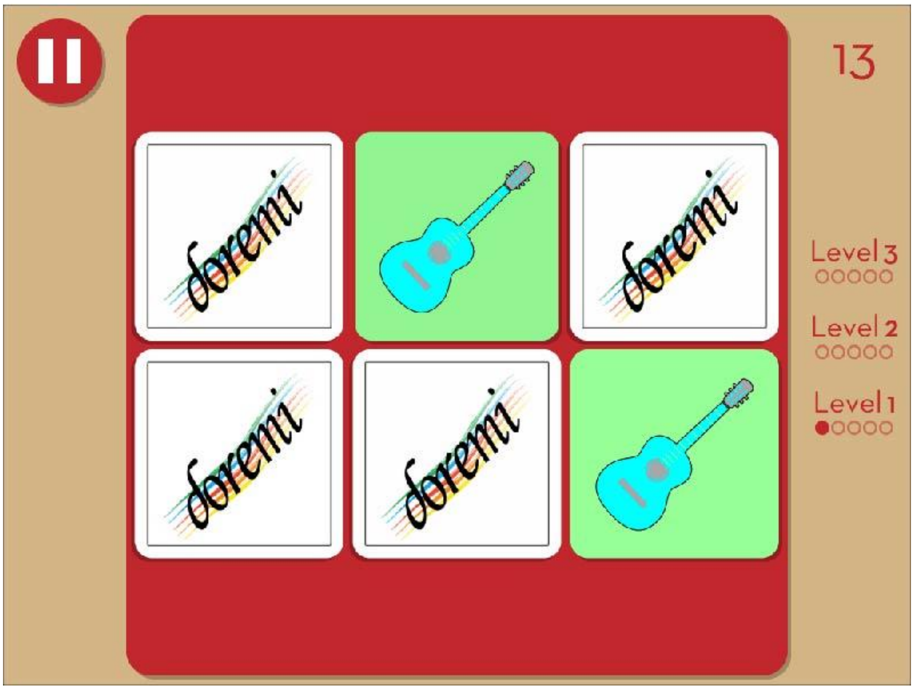

Figure 26 - During play, the player will receive visual, auditory and haptic feedback as to whether they are right or wrong.

4.3. Solve it! game

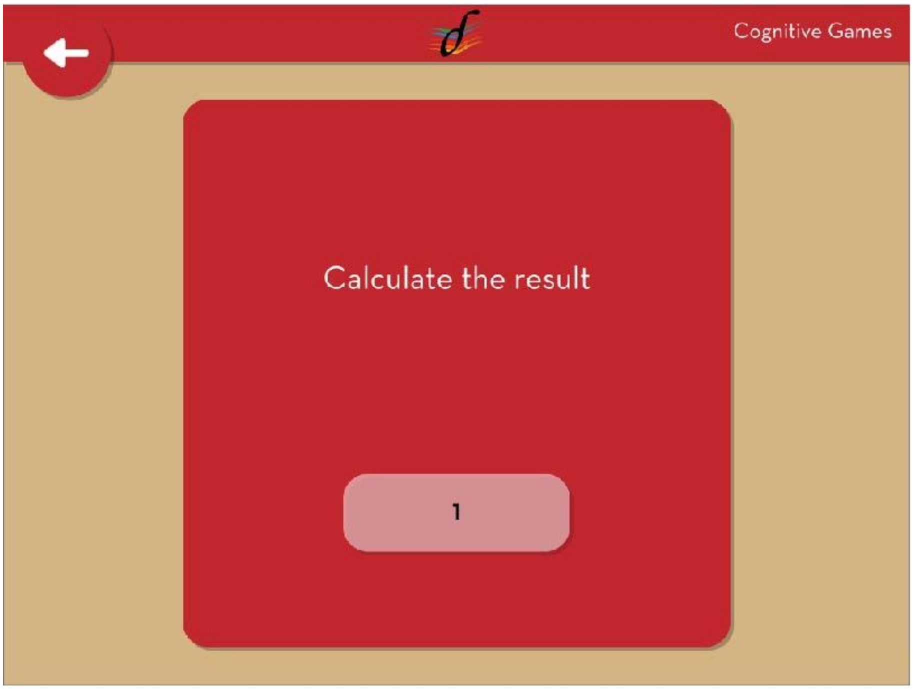

Figure 27 - At the start of the game, instructions are presented to the player, explaining the objective of the game and how to play it.

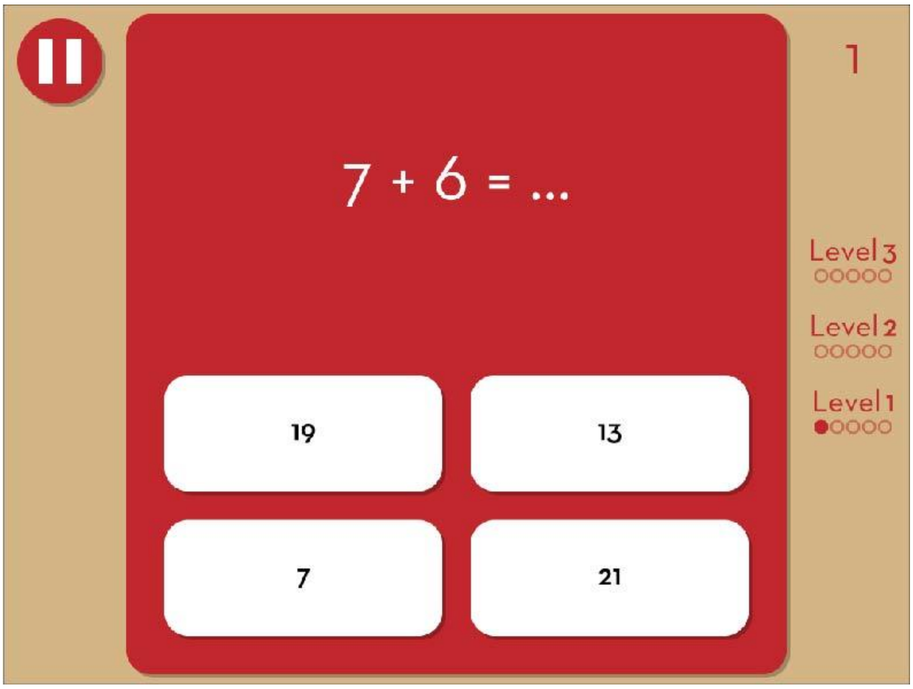

Figure 28 - On the screen, an arithmetic operation, and four possible results are presented.

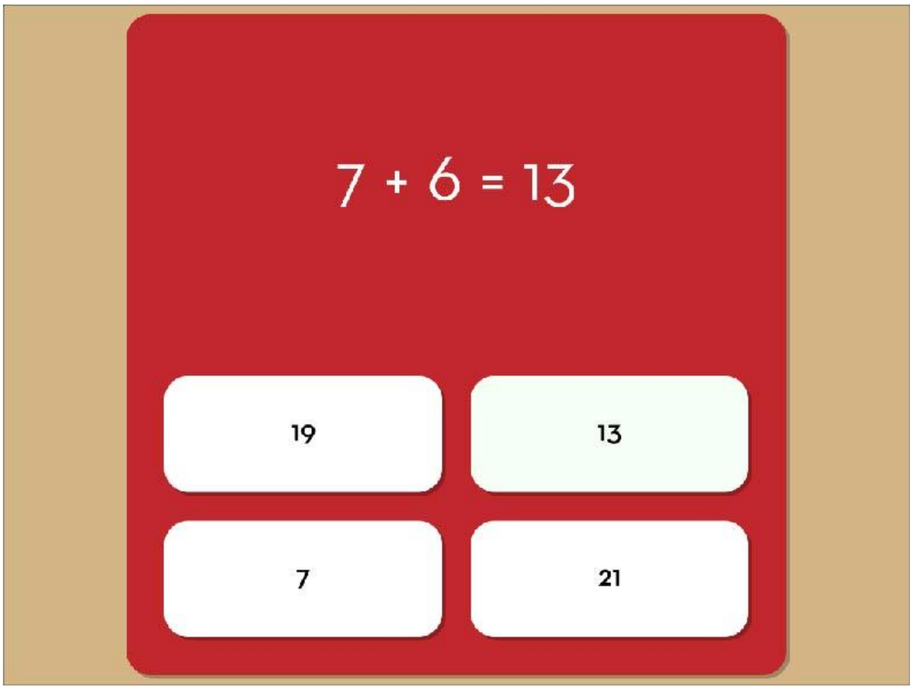

Figure 29 - If the player chooses the correct result, it is displayed at the end of the arithmetical operation, on the top of the screen. The player also receives visual, auditory and haptic feedback as to whether the selected answer is correct or incorrect.

4.4. Complete it!

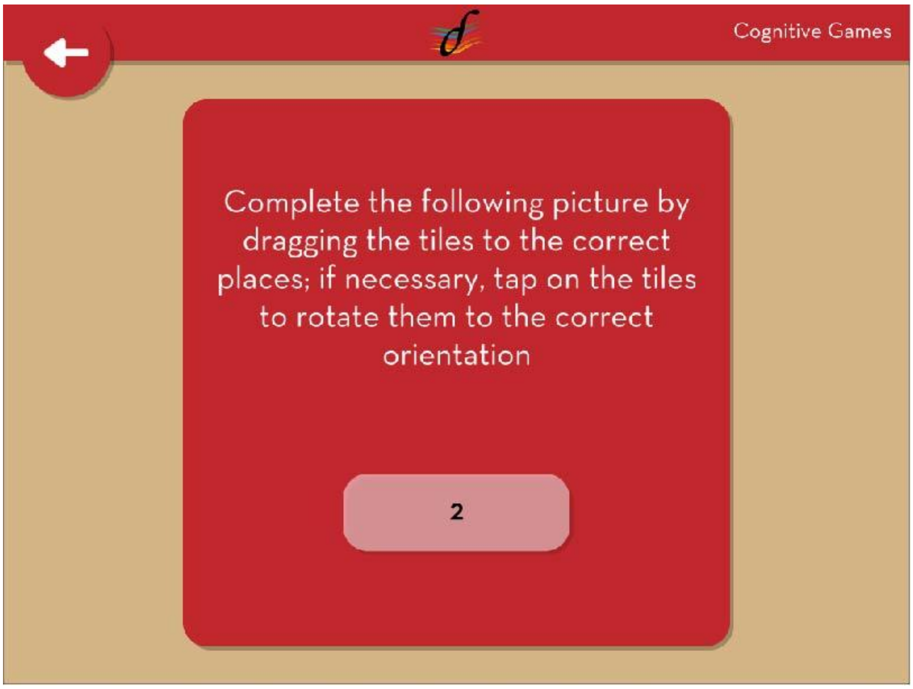

Figure 30 - At the start of the game, instructions are presented to the player, explaining the objective of the game and how to play it.

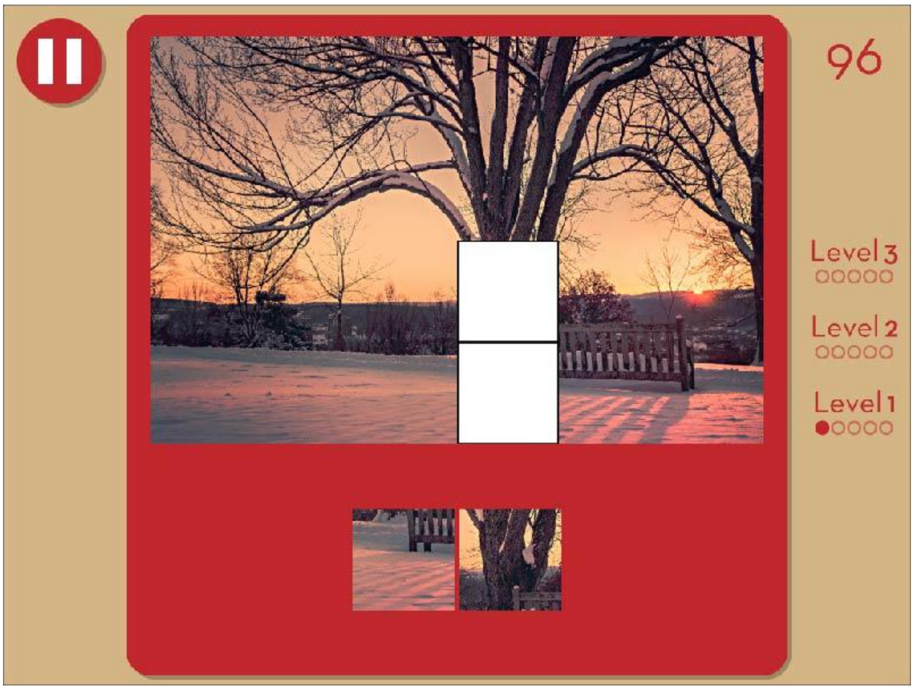

Figure 31 - An image is presented on the screen. Within the image there are various empty spaces and at the bottom of the screen, various tiles that can be rotated or dragged to an empty space within the image.

Figure 32 - If the player drags a tile to the correct place but with the wrong rotation, the tile is locked in the position but a red halo suggests that something is wrong.

Figure 33 - If the tile is dragged to the correct position and with the correct rotation, a green halo indicates that it is correct and the tile will be completely locked in position. As for the other games, the player receives visual, auditory and haptic feedbac

6. CLINICAL IMPLICATIONS

5.1 Cognitive Games for Active and Healthy Aging

The aging of the population is a growing and relevant issue for the European countries: in 2050, the EU population over 60 will be 35% [1]. Related to the global ageing of the population, health trends are changing and mild disability and chronic diseases are increasing [2], causing a consequent increase of the long-term costs, particularly for pathologies that represent high rates of dependency, like dementia. The ageing population will not lead inevitably to higher health care costs if preventive measures will be taken and older people are empowered to manage their own health. Dementia refers to a diagnostic category that includes several disorders (e.g. Alzheimer's disease, front-temporal dementia) each one sharing the one central feature the progressive decline of cognitive functions, such as memory, language and attention. About 6 percent of over 60s in European countries are affected by dementia and trend research indicates that the rate is constantly growing. [3]. According to OECD estimations in 2012, France, Italy, Spain, Sweden and the UK had the highest prevalence, with 6.3% to 6.6% of the population aged over 60 affected by dementia. Due to the debilitating nature of dementia, people with this disease become increasingly dependent on their caregivers and require assistance in conducting even the most basic daily activities. As a result of the increased pressure, people caring for patients with dementia are at higher risk of depression, anxiety and reduced quality of life [4]. Due to the high impact of dementia on the quality of life of people affected, their caregivers and the healthcare system, many studies during the last decade have been conducted to enable understanding of early predictors and risk factors of the disease. A key risk factor for the incidence of dementia is cognitive decline [5] and one way of managing dementia is to design interventions, which target people with early signs of cognitive impairment, before dementia develops. Cognitive decline refers to changes in cognitive functions, which are more pronounced than would be expected within the spectrum of normal ageing. Cognitive decline can affect one or more cognitive functions including memory, orientation, language and executive functions. The prevalence of cognitive decline is 10.7% of the population, increasing with age, and higher in women [6].

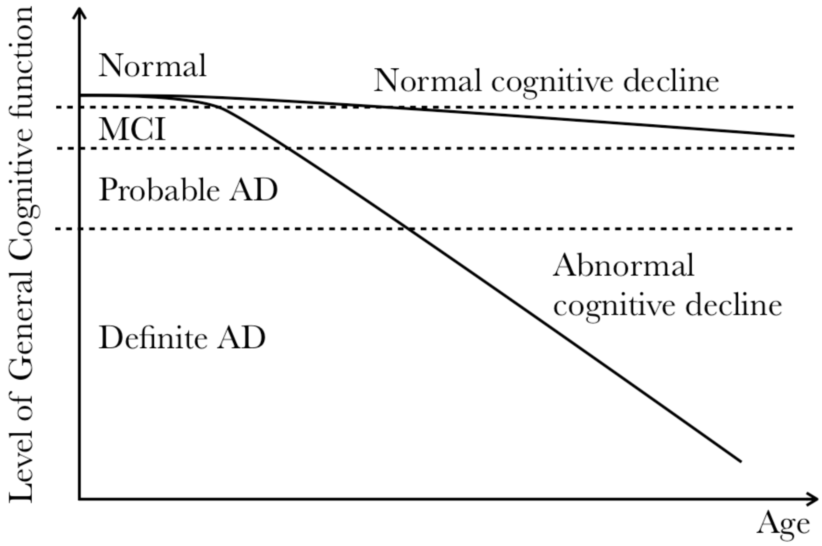

Figure 34 - Instance of class Action

The probability of developing cognitive decline is associated with numerous risks factors, such as tobacco use, the Apo lipoprotein E _4 genotype, and certain medical conditions, as well as protective factors, like cognitive training and physical exercise [6]. The “use it or lose it” theory applied to the study of cognitive science during ageing has been circulated in recent years, not only in the scientific community but also in the wider public, as evidenced by the numerous popular self-help books that encourage readers to maintain “active mind” [7].

The scientific community has confirmed this hypothesis. Numerous studies both, epidemiological and clinical show that people who lead a mentally engaged lifestyle are less likely to develop cognitive decline and dementia [8]. Activities that have been reported to be protective against cognitive decline include leisure time, learning a foreign language, playing puzzles, crosswords etc. The assumption underlying the “use it or lose it” hypothesis is related to the theory of cognitive plasticity, which refers to the capacity of the brain to change its structure and functionalities on the basis of the stimuli and the requests of the environment and is connected to the theory that the brain is able to develop and adapt throughout the whole lifespan [9]. This theory has been confirmed by several studies in animals and humans and has been used to investigate the potential of the brain to prevent and recover from a decline in cognitive function [10].

Although many EU states have prioritised the assessment and diagnosis of cognitive decline (for instance by developing guidance about diagnostic criteria), preventive interventions for older people tend to be less well developed. Methods typically used in research and clinical practice to improve or maintain cognitive functioning can be categorised into cognitive stimulation, cognitive training and cognitive rehabilitation [11]. These terms are not interchangeable; cognitive stimulation usually involves group activity aimed at stimulating cognitive and social functioning; cognitive rehabilitation is an individualised approach which may involve training with a therapist using mnemonic strategies and, finally, cognitive training, which involves guided repetitive practice on a set of tasks which have been designed to reflect particular cognitive functions such as memory, attention, language and executive functioning. It is argued by Gates, Sachdev, Singh and Valenzuela [12] that this lack of a formal distinction between types of cognitive intervention can explain the inconsistent effectiveness of interventions using cognitive training reported in the scientific literature. In a true cognitive training intervention, participants are typically assessed using neuropsychological tests at baseline before completing a fixed number of cognitive training sessions (targeting one specific area of cognition or multiple areas). The desired outcomes of cognitive interventions for people with cognitive impairments are two-fold. First, the immediate effects of improved cognition could positively affect functional abilities, psychological wellbeing and quality of life. Second, cognitive interventions could delay the progression of cognitive decline, which in turn has benefits for the individual, their family and public health systems [11]. In the scientific literature, there have been some successful attempts to apply computer based cognitive training to improve cognitive functioning in older adults. The Plasticity-based Adaptive Cognitive Training (IMPACT) study trained 487 adults without cognitive impairment and aged >65 using Brain Fitness Program [13]. The intervention comprised a series of six computerised exercises designed to improve speed and accuracy of auditory information processing. Following 40 hours of training (1 hr per day, 5 days a week for 8 weeks), participants showed significant improvements in the trained area of auditory memory and attention, in addition to improvements in untrained areas, including working memory, delayed recall and processing speed.

The Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) trial [14] is a further example of successful cognitive training for cognitively normal older people involving more than 2500 people using both computerised and non-computerised activities. Significant improvements were found for group training for verbal episodic memory, reasoning exercises and computerised speed of processing training (visual search and identification of a stimuli), compared to a no-contact control group. There is less published research on cognitive training for people with cognitive impairment. A meta-analytic review of 15 published cognitive interventions for people with cognitive impairment found that people undertaking a cognitive intervention significantly improved in global cognition, episodic memory and executive functioning compared to control groups [15]. Although not reaching statistical significance, the following areas of interest all showed increases greater than that of the control group following cognitive training: Global cognition, measured by the Mini Mental State Examination , semantic memory, attention/processing speed, visuo-spatial ability, language; activities of daily living, depression and anxiety. A criticism of this review is that it included studies, which used cognitive stimulation and rehabilitation techniques, in addition to those using cognitive training (making it difficult to partial out the benefits of cognitive training). In a more strictly defined review of cognitive training for people with cognitive impairment, cognitive training interventions were shown to have moderate-large beneficial effects on memory outcomes. Evidence suggests that computer based interventions could provide a solution for improving cognitive health in older adults [16].

5.2 Cognitive games

Despite videogames usually being designed for young people, their wide distribution and availability has led to them also being targeted towards older users. A report in 2012, by the Electronic Software Association indicated that 49% of households own a game console and play games on portable devices [17]. The widespread use of portable devices including: smart phones, tablets, and personal computers, will enable games to be aimed at wider target markets.

The aims of these games are variable and include: games for fun, games created to entertain the users, and serious games, designed to produce positive effects for the end users. Serious games, as described in Deliverables 5.1 and 5.2, can be applied in various fields, including health. Furthermore, health sectors can be divided into several intervention fields, as shown by the DOREMI project. Cognitive games are one of the possible areas of application that have received strong attention by the media, as shown in D5.1. These types of games often refer to the ability to train cognitive functions. One of the most relevant issues that arose when analysing the literature on the theme is that most of the cognitive games currently on the market are designed for general use and do not take into account older adults. Designing games based on older users' needs is a distinctive challenge that needs to take into consideration the possible limited experience of older users with gameplay interface and convention.

Games for cognitive decline can be categorized based on the area of intervention such as cognitive, physical and social/emotional. Here only cognitive games will be described, being the main topic of this paragraph. As described in McCallum and Boletsis's [18] review, there is a wide variety of serious games targeted at dementia prevention including: WiiFit, Wii Sports, Big Brain Academy, Lumosity, Posit Science, Complete Brain Workout, SmartBrain Games, MasterQuiz, Xavix Hot Plus and MinWii (MINDs). These games are wide spread and applied in clinical settings, but there are still few experimental studies that investigate the efficacy of training based on serious games in preventing cognitive decline.

Some of them such as Big Brain Academy, SmartBrain Games, Complete Brain Workout MinWii (MINDs) and Posit Science show a strong impact on various aspects of cognition such as attention, verbal memory, visuospatial and constructive function, reminiscence and memory related abilities and reduce the rates of cognitive decline [18]. Some of them have shown indirect effects on other aspects of health status such as behaviour and depression using Big Brain Academy, mood using Lumosity, Activity Daily Living using Complete Brain Workout, and sociability using Xavix Hot Plus[18].

Fernandez-Calvo and collaborators [19] conducted a study to assess the efficacy of cognitive game training, compared toIntegrated Psychostimula-tion Program (IPP), for the duration of 12 weeks, involving 45 subjects with Alzheimer disease. The 'game' program was more effective than the 'traditional' one to reduce cognitive decline and depressive symptoms in patients with AD.

Tarraga et al. [20] conducted a randomized pilot study to test the efficacy of the interactive multimedia internet-based system (IMIS) involving 46 mildly impaired patients receiving stable treatment with cholinesterase inhibitors (ChEIs). The IMIS encompassed 19 stimulation exercises covering various domains of cognition. The IMIS was applied within the daycare center for a period of 26 weeks produced an improvement in cognition in patients with Alzheimer disease.

Finn et al. [21] investigated the efficacy of a cognitive training (30 sessions in an average of 11.43 weeks) based on Lumosity involving 25 subjects affected by MCI. The results of the study show an improvement of performance across a range of cognitive tasks related to the training. Barnes [22] conducted a pilot randomized controlled trial to test a cognitive training (5 sessions per week for 6 weeks) based on Posit Science, comparing its effects on cognitive functions with waiting list control. The results show that training based on Posit Science is feasible in at least a subgroup of people with MCI. Another randomized pilot experiment was conducted by Rosen [23] to test a cognitive training (5 sessions per week, total of 24 sessions) based on Posit Science involving MCI patients and investigating its impact on memory and other cognitive functions. The results show that Posit Science training positively affects memory functions. However, due to the small sample size statistical significance was not reached.

In 2011 Yamaguchi et al. [24] conducted an interventional study to test a cognitive training (1 session per week for 10 weeks) using Xavix Hot Plus and involving 9 subjects affected by Alzheimer disease. The results showed improvements in cognitive functions in general and particularly in the visuospatial and constructive function. Some of these games try to address the issue of ecological validity frequently present in cognitive assessment and training. Imbeault and collaborators [25] developed a test based on the Naturalistic Action Test (NAT) where users must point and click objects on the screen to complete the stages of a real-world task such as preparing tea by clicking milk, sugar, water in the correct order. Hodges [26] tested SenseCam a wearable camera which takes automatic photographs by responding to environmental changes (e.g., detection of a person in front of the camera or a change in light). Following the use of the Sensecam and by reviewing the pictures periodically, subjects were able to reinforce an autobiographical account of events over the past months, but no quantitative trial data to support the use of the product exist.

Nevertheless, also games designed to train physical and cognitive functions may have a side effect on emotional/social health status. There is still a big gap to fill between the wide application of serious games to prevent cognitive decline and the results about their efficacy. The next challenges to be carried out by researchers and clinicians should be:

- investigating the correlation between ICT data and results obtained by classical assessment tools;
- collecting long-term data about behavioural and psychological symptoms of dementia;
- capturing the patients' performances and actions in real time and real life situations using ICT devices;
- developing simple devices with easy and understandable scores in comparison to the present tools;
- design games based on users' needs and capabilities.

5.3 Designing cognitive games for active and healthy aging

Over the last few years there was an increasing diffusion of the serious games aiming to intervene and ameliorate various aspects of the health of the subjects. Such games found a wide field of application in Alzheimer disease and cognitive decline prevention. Most of them are not designed basing on Alzheimer user needs but with a "typical user" in mind, as confirmed by studies that reports a number of usability problems. As highlighted by Legouverneur and collaborators [27] serious games could have a positive impact on cognitive and motor skills, but there are still several usability problems related to design aspects not targeted neither for the older people neither. A recent report by Mc Laughlin et al. [28] shows that the main reasons why the older users are not interested in playing games are: stereotypes (self though about inability), exceeding cognitive accessibility (exceeding of cognitive demand request) and the difficulties related to the User interface. Moreover, cognitive changes in aging can affect the effect of some games information including punishments, goals and rewards that are fundamentals in motivating users in game experience. User needs analysis, usability tests and design based on recommendations for specific user targets for Alzheimer disease subjects [29], will be the key elements for future serious games for older people affected by cognitive decline and researchers.

Changing in physical functionalities during aging can affect the user experience of the game, reducing engagement, accessibility and game usability. As described in D5.1 the international guidelines were taken into account to make the USER INTERFACE accessible for older users.

5.4 Description of the cognitive game of the DOREMI platform

As described above the cognitive games currently on the market have several limits due to design issues related to the lack of usability and accessibility, and often are not based on scientific knowledge of cognitive science. In the following sections the games developed for the DOREMI project will be briefly described.

FIND IT!

This game was designed to train several cognitive functions including: visual attention, working memory, alertness, and inhibition. The games require the subject to look for one or more items in the display and touch it. Find it! game is based on one of the most used and important experimental paradigm of cognitive science: the Visual search task. Visual Search is one of the most studied and known cognitive tasks (for a recent review see Eckstein [32]) and is derived from the common real-world task of looking for a visually distinguished object in the surroundings. Its relevance in the scientific field is strictly related to its emerging importance in the conduct of daily activities. For example, someone searching for an object in a room such as a key or a journal in a room full of objects (*set size*). This person needs to retain in memory the information regarding the *target,* such as physical characteristics, and examine the environment, excluding all the items that have different shape size and colour from the target one (*physical distractors*). It could be that there are other journals in the same room, so the subject would have to exclude journals that are not the target one (*semantic distracters*). Detection recognition and identification of items in visual field, as described above, is one of the most used cognitive paradigms, and there are several theories that try to explain how this process is completed. The visual search task requires the use of a wide range of cognitive functions including: alertness, visuospatial attention, executive control, inhibition and memory, and implies the involvement of several brain associated areas including thalamus-frontal, ventral frontotemporal, and dorsal frontoparietal brain networks [32].

In the following section, some of the characteristics of the tasks that can affect the ability of the subject to detect the target among distractors are presented. The difficulty level during the game in based on increasing several aspects of the game that scientific literature shows to make this task more difficult for healthy but most of all for MCI subjects:

Table 1 - FIND IT! cognitive game features

Feature	Cognitive definition/construct/effect	Effect on performance	Application in the FIND IT game
conjunction feature	The combination of two or more primary visual features such as	In comparison with Single feature search conjunction	All the stages will require conjunction

search	colour and form (e.g., looking for something red and round).	feature tasks are, affected by cognitive decline and can be impaired in MCI subject [34].	feature search because the performance on simple feature task is not generally impaired in MCI and cognitive declining process of aging.
Set size	The amount of items displayed in the visual field.	MCI and AD subjects shows a reduction in the ability to exhibit impaired inhibitory control [35].	The difficulty levels will be increased by raising the number of the item displayed in the visual field.
Location of targets in the space		Performance of MCI subjects in visual search tasks deteriorates as the target is presented at farther peripheral locations, and this effect becomes more pronounced with greater set size [36].	The difficulty level of the game will increase based on the location of the target on the display.
Number of instructions requested	Working memory is the "brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning" [37].	In MCI subjects, working memory is one of the cognitive functions that show significant decline [38].	The amount of temporary storage information required will be increased through the levels to increase the difficulty level.
Type of distractors	Interference is one of the most studied phenomena in visual search tasks. It refers to the difference effect in reducing response accuracy and reaction time of the type of stimuli used as distractors.	In particular those distractor stimuli that are similar in physical or semantic characteristics to the target ones will increase the interference effects and reduce the performance of the subject [39].	The difficulty level will be increased by increasing the number of semantic and colour related distractors.

__MATCH IT!__

The main aim of the MATCH IT game is to train and stimulate Visual Spatial Short Term Memory (VSSTM) and Working Memory (WM). STM is traditionally defined as the amount of information that a person can retain over a brief interval of time. The most common method for measuring the capacity of STM is the span task [40], which consists of presenting a series of verbal or visuo-spatial items and then requesting the subject to recall it. The length of the list increases from the minimum number to and higher one. The span of the STM is considered the highest number of items remembered. WM instead is defined as the ability to process information during the execution of a task. WM and VSSTM are some of the memory components that can be affected by cognitive decline and that is impaired in AD [41] and affect the patients' activities in daily living. Several studies have found impairment in VSSTM in both very mild and mild AD patients [32]. Faust and Balota [32] suggests that it might be one of the early predictors of cognitive decline. Memory impairments impact on everyday tasks that often require learning and retention of verbal or non-verbal information. The identification of WM as a central component of cognition has introduced the possibility that focused, theoretically motivated techniques for training broad abilities can be developed.

This game has the aim to train VSSTM and WM. The game is a variation on a pair matching task, where players are required to remember the location of an increasing number of paired items on a grid. As described for the FIND IT game the performance of the subject is affected by the variation of several variables. These ones have been used to increase the difficulty level of the game.

Table 2 - MATCH IT! cognitive game features

Feature	Cognitive definition/construct/effect	Effect on performance	Application in the FIND IT game
Span	Number of items stored and remembered.	During aging, the span is progressively affected and can be reduced in MCI subjects.	Increasing the number of pairs that participants are requested to detect during the task will increase the difficulty of the game.
Interference, number of distractors	Color and semantic interference effect distractors that are semantically related, to targets can affect target selection performance	In particular, those distractor stimuli that share similar physical or semantic characteristics with the target ones increase the interference effects and reduce the performance of the subject.	The interference effect was used, as described above, also in this game. In particular, the difficulty of the game will increase raising the number of semantic related pairs.

Storage time	The amount of time during which the information to be stored is available.	The less time during which the information to be remembered is available more is difficult to recall from memory.	The number of seconds that the subject has to store the information related to the position of the pairs will be reduced to increase the difficulty of the game.
Retention time	The amount of time passing from the moment when the information is available until it is possible to respond.	Increasing the amount of time during which the information is to be retained without the possibility to respond will reduce the performance levels.	The retention time will be increased to raise the difficulty level of the game.

CALCULATE IT!

The cognitive functions that will be stimulated by the third cognitive game include: the ability to process numbers, understand them and perform calculations. They can be considered different components and usually in cognitive science can be indicated as number processing system and calculation systems. The first one includes the comprehension and production of numbers, while the last one comprehends the facts and procedures used to carry out a calculation.

Table 3 - Calculation components

Types	Description
Number-Processing System	Cognitive structuring of the numerical components: mechanisms of quantification, seriation, understanding, strategies for mental calculation.
The calculation system	Procedural level: reading, writing, and queuing of numbers, recovery of numeric facts and algorithms of the written calculation.

The Number-Processing System can be divided in to components dedicated to number production and comprehension. Moreover, it is possible to distinguish between components that are responsible for processing Arabic (such as 435) or verbal numbers (numbers in the form of spoken or written number words). The number processing function can also include a distinction between lexical-processing and syntactic-processing components. The lexical component is related to the understanding and production of single elements in a number (the digit 3 or the word three), while the Syntactic processes are related to the relations of the elements that compose a number. For example the association between the position of the number and its meaning regarding thousands, hundreds, and decimals. The last distinction that can found in the number processing component is related to the means used to understand or produce that can be in written or oral form (graphemes or phonological).

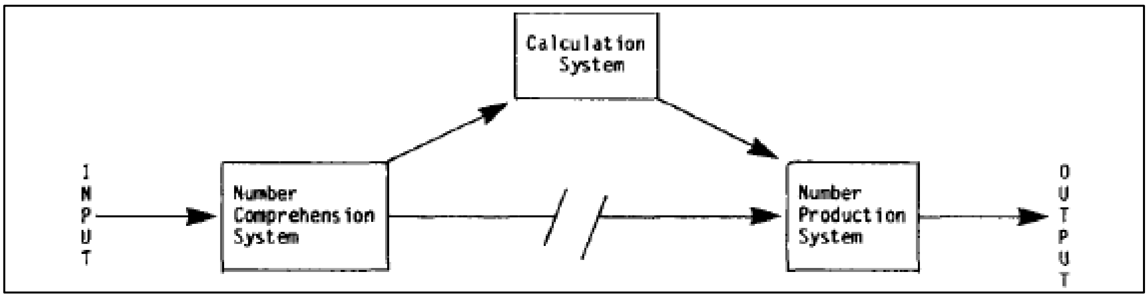

Figure 35 - Schematic representation of number-processing and calculation systems.

The calculation system can also be divided into several components including: processing of operational symbols, such as + - /, the retrieval of basic arithmetic facts (table facts such as 6 x 7 = 42), and execution of calculation procedures. Despite this division of components and subcomponents the systems described briefly above are not totally separate, in fact a damage to the component described above that are fundamental to comprehend numbers, affects the ability to understand and produce calculation. Calculation deficits can be present in MCI and AD subjects [43] affected by cognitive decline and can have an impact on daily tasks. Calculation and number processing deficit has been found to be strictly related to the degree of cognitive impairment and can deteriorate in a hierarchical way, involving first of all the more complex calculation skills passing then to the more basic ones.

The aim of the game is to train number processing and calculation functions. During the task participants will be required to make some operations and select the correct result among the possible solutions proposed. The difficulty level will increase step-by-step, by modifying some variables and increasing the cognitive load required by the participant, as described in table 3 below:

Table 4 - CALCULATE IT! cognitive game features.

Feature	Cognitive definition/construct/effect	Effect on performance	Application in the CALCULATE IT game
Type of operation	Different type of operations require different levels of cognitive load and the involvement of different cognitive functions in the	Addition and subtraction are considered easier, while multiplication and division require a higher cognitive load.	The level of difficulty will be increased by increasing level of cognitive load.

	calculation.		
Length of Operand	Each element on which is carried out the operation. For example in the operation 5 + 1, the numbers 5 and 1 are the operands	The number processing components include cognitive mechanisms mediating comprehension and production of both Arabic numbers and number words, in particular syntactic-processing components. The difficulty in understanding and processing numbers are strictly related to the length of the number because it involves a higher request for syntactic-processing and working memory components.	Increasing the lenght of the number will increase the level of difficulty.
Number of Operators	It is a symbol that specifies which law applies to one or more operands, to generate a result (e.g. +; -).	Process operations which include more than two operators require an effort for the working memory which involves retaining in memory the results of the first operation and manipulating this information mentally to produce the final result of the operation.	During the game the number of operators will be increased to arise the working memory effort required.
Number distance	It is the amount of numbers that separate one number from another.	In cognitive science it is known as the distance effect in number comparison [44] and indicates that discriminating two numbers that are numerically far apart is easier than discriminating numbers that are numerically close. One of the explanations for this effect is	During the game the distance between the target number and the distractor ones will be reduced progressively requiring the subject to compare between nearer numbers.

		that the numbers are ideally placed in a continuum [45].	

COMPLETE IT!

The fourth game has the main aim to train and detect constructional apraxia and visuo-spatial abilities. The game request is to complete the image depicted in the display using the pieces of image that are showed in the selection side. In literature, some tasks that require to compose different shapes using several parts have been analyzed. One of the most studied is Block Design tests, in which examinees copy abstract designs using colored blocks, have long been popular indices of intelligence [46] and neuropsychological functioning [47]. In clinical settings it is currently used to test and train the constructional praxia. This construct has been given various definitions during its history. The most popular and used definition of constructional praxia is by Kleist who defined it as ‘‘the ability to do a construction’’. In contrast, Benton defined constructional apraxia as ‘‘the impairment in combinatory or organizing activity in which details must be clearly perceived and in which the relationship among the component parts of the entity must be apprehended’’ [48].

Theorists have proposed that subjects use two distinct strategies in solving block designs. In the analytic strategy, the displayed design is mentally segmented into units corresponding to block faces, then the blocks are directly placed, one by one, to match each unit. In the synthetic strategy, the design is viewed as a whole and is not differentiated into units corresponding to block faces; instead, the blocks are manipulated until they match the pattern or seem to "click" with adjoining blocks to reproduce the design.
Thus, the synthetic approach focuses on the gestalt of the stimulus pattern and matches this overall design.
Subjects affected by AD with constructional apraxia show several impairments in visual spatial tasks including perspective deficit and spatial alterations. Despite some patients still preserve the ability to perform several constructional tasks, this type of deficit has be considered one of the possible indicator of the disease onset.

.

We propose that the difficulty of an overall construction problem can be represented as the sum of the difficulties of selecting and placing the individual pieces in the construction.

Table 5 - COMPLETE IT cognitive game features.

Feature	Cognitive definition/construct/effect	Effect on performance	Application in the CALCULATE IT game
Image composition	Gestalt effect. The ability to generate a whole forms recognizing a global figures instead of unrelated pieces.	Increasing the number of pieces that are extracted from the image reduces the gestalt of the picture.	The difficulty level is increased by increasing the number of pieces extracted from the image.

Number of distractors	Interference is the competition created between different choice or type of information.	It refers to the effect of reducing response accuracy and reaction time due to the presence of distractors and information that are competing with the target one.	The difficulty of the game will increase by raising the number of distracters.
Items Rotation	Mental rotation is the ability to rotate mental representations of two-dimensional and three-dimensional objects as it is related to the visual representation of such rotation within the human mind.	The reaction time for participants to decide if the pair of items matched or not is linearly proportional to the angle of rotation from the original position.	The difficulty level will be increased by increasing the angle of rotation of the items.

7. TECHNICAL ASPECTS

6.1 High level game server and reasoning engine integration

A high level diagram of data flows between the Gamified Environment and the DOREMI backend (Game Server) has been designed and is general enough to support the plugging in of further games in all the three DOREMI sections (Cognitive Games, Exercise Area and Social Area).

Following physicians' and expert' inputs the engineering team designed the overall structure illustrated in the picture below:

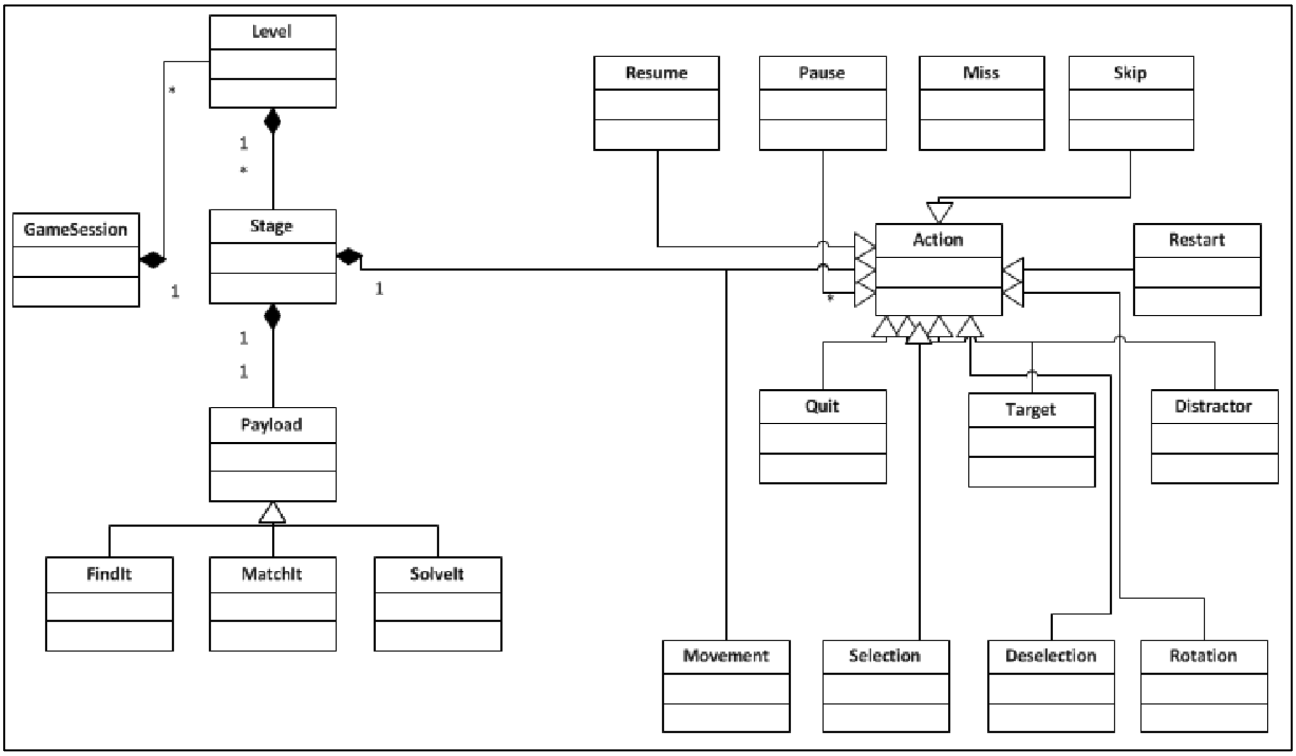

Figure 36 - Data structure

Each game has been analysed and the main entities involved for data representation identified. Every day a Game Session is started for each game required from the Patient records.

Each Game Session consists of a set of levels and each level is composed by several stages. During each stage any action the user performs will be categorized and stored locally on the tablet.

Once the user has completed one stage, data are sent back to the Game Server, then the current status of the Gamified Environment and the reasoning engine KIOLA will be both updated for further reasoning.

The data stream exchanged between Game Server and KIOLA is in JSON format and is called "*observation*".

Observations are documented in AIT specifications which will be included in D4.2 and are sent to KIOLA from the Game Server using the KIOLA API described in the same document. For convenience an example of an observation can be found in Appendix 1.

Every time a stage is completed the whole set of recorded user interactions will be sent to the game server and to KIOLA for storage and future reasoning.

This kind of behaviour has been specifically designed in order to: minimize the data transfer exchange, and decrease bandwidth usage, battery drain of the tablet and latency in the user interaction of the game.

On the other hand, sending a bulk set of information would involve a heavy load of data to be sent in a single time point, augmenting the risk of information getting lost and the application crashing. As a result, the user's performance data for that day could be lost.

With the implemented approach, in case theApp crashes or network becomes disconnected, the user will be able to start again from the stage where he left.

6.2 Cognitive Area structure

The cognitive area follows the general structure of dataflow. It contains also raw data coming from the Gamified Environment which will be stored for further clinical analysis as it has great value providing a direct comparison to literature values for reaction time and behaviours.

Samples of the dataflow for the cognitive games, following the general model, are provided in table format.

ACTION EXAMPLE		
VARIABLE	**TYPE**	**DESCRIPTION**
uid	guid	User id
timestamp	timestamp	Time when action is executed
rel_time	milliseconds	milliseconds since the start of the stage
action id	guid	Action id
stage ref (stage id)	ref	Stage id
type	categorical nominal	target / distractor / miss / pause / resume
payload	object	TARGET EXAMPLE

Figure 37 - Instance of class Action

8. REFERENCES

[1] Rechel, B., Grundy, E., Robine, J. M., Cylus, J., Mackenbach, J. P., Knai, C., & McKee, M. (2013). Ageing in the European Union. *The Lancet*, *381*(9874), 1312-1322.

[2] Rechel, B., Doyle, Y., Grundy, E., & McKee, M. (2009). How can health systems respond to population ageing?

[3] Wimo, A., Winblad, B., & Jönsson, L. (2010). The worldwide societal costs of dementia: Estimates for 2009. *Alzheimer's & Dementia*, *6*(2), 98-103.

[4] Pinquart, M., & Sörensen, S. (2006). Helping caregivers of persons with dementia: which interventions work and how large are their effects?.*International Psychogeriatrics*, *18*(04), 577-595.

[5] Plassman, B. L., Williams, J. W., Burke, J. R., Holsinger, T., & Benjamin, S. (2010). Systematic review: Factors associated with risk for and possible prevention of cognitive decline in later life. Annals of Internal Medicine, 153(3), 182–193. doi:10.7326/0003-4819-153-3-201008030-00258

[6] Carlo, A., Baldereschi, M., Amaducci, L., Maggi, S., Grigoletto, F., Scarlato, G., & Inzitari, D. (2000). Cognitive impairment without dementia in older people: prevalence, vascular risk factors, impact on disability. The Italian Longitudinal Study on Aging.*Journal of the American Geriatrics Society*, *48*(7), 775-782.

[7] McKhann, G., & Albert, M. (2002). Keep your brain young: The complete guide to physical and emotional health and longevity. John Wiley & Sons.

[8] Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. The Lancet Neurology, 3(6), 343-353.

[9] WHO, Active Ageing, WHO, Geneva, Switzerland, 2002.

[10] Mercado, E. (2009). Cognitive plasticity and cortical modules. Current directions in psychological science, 18(3), 153-158.

[11] Clare, L., Woods, R. T., Moniz Cook, E. D., Orrell, M., & Spector, A. (2003). Cognitive rehabilitation and cognitive training for early-stage Alzheimer's disease and vascular dementia. Cochrane Database Syst Rev, 4.

[12] Gates, N. J., Sachdev, P. S., Singh, M. A. F., & Valenzuela, M. (2011). Cognitive and memory training in adults at risk of dementia: a systematic review. BMC geriatrics, 11(1), 55.

[13] Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., & Zelinski, E. M. (2009). A cognitive training program based on principles of brain plasticity: Results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) Study.Journal of the American Geriatrics Society, 57(4), 594-603.

[14] Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., & ACTIVE Study Group. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. Jama,296(23), 2805-2814.

[15] Li, H., Li, J., Li, N., Li, B., Wang, P., & Zhou, T. (2011). Cognitive intervention for persons with mild cognitive impairment: A meta-analysis. Ageing Research Reviews, 10(2), 285-296.

[16] Musian, D. & Ascolese, A. (2015). Gamified Cognitive Training to Prevent Cognitive Decline. In D. Novák, B. Tulu, & H. Brendryen (Eds.), Handbook of Research on Holistic Perspectives in Gamification for Clinical Practice. Hershey, PA: IGI Global.

[17] Nonprofit Report for ENTERTAINMENT SOFTWARE ASSOCIATION. Guidestar.com. Retrieved on 2013-08-23.

[18] McCallum, S., & Boletsis, C. (2013). Dementia Games: a literature review of dementia-related Serious Games. In Serious Games Development and Applications (pp. 15-27). Springer Berlin Heidelberg.

[19] Fernández-Calvo, B., Rodríguez-Pérez, R., Contador, I., Rubio-Santorum, A., & Ramos, F. (2011). Efficacy of cognitive training programs based on new software technologies in patients with Alzheimer-type dementia. Psicothema, 23(1), 44-50.

[20] Tárraga, L., Boada, M., Modinos, G., Espinosa, A., Diego, S., Morera, A., ... & Becker, J. T. (2006). A randomised pilot study to assess the efficacy of an interactive, multimedia tool of cognitive stimulation in Alzheimer's disease. Journal of Neurology, Neurosurgery & Psychiatry, 77(10), 1116-1121.

[21] Finn, M., & McDonald, S. (2011). Computerised cognitive training for older persons with mild cognitive impairment: a pilot study using a randomised controlled trial design. Brain Impairment,12(03), 187-199.

[22] Barnes, D. E., Yaffe, K., Belfor, N., Jagust, W. J., DeCarli, C., Reed, B. R., & Kramer, J. H. (2009). Computer-based cognitive training for mild cognitive impairment: results from a pilot randomized, controlled trial. Alzheimer disease and associated disorders, 23(3), 205.

[23] Rosen, A. C., Sugiura, L., Kramer, J. H., Whitfield-Gabrieli, S., & Gabrieli, J. D. (2011). Cognitive training changes hippocampal function in mild cognitive impairment: a pilot study. Journal of Alzheimer's Disease, 26(3), 349.

[24] Yamaguchi, H., Maki, Y., & Takahashi, K. (2011). Rehabilitation for dementia using enjoyable video-sports games. International Psychogeriatrics, 23(04), 674-676.

[25] Imbeault, F., Bouchard, B., & Bouzouane, A. (2011, November). Serious games in cognitive training for Alzheimer's patients. In Serious Games and Applications for Health (SeGAH), 2011 IEEE 1st International Conference on (pp. 1-8). IEEE.

[26] Hodges, S., Berry, E., & Wood, K. (2011). Sense-Cam: A wearable camera that stimulates and rehabilitates autobiographical memory. Memory (Hove, England), 19(7), 685–696.

[27] Legouverneur, G., Pino, M., Boulay, M., Rigaud, A. (2011). Wii sports, a usability study with MCI and Alzheimer's patients. Alzheimer's & dementia: the journal of the Alzheimer's Association, 7, 500-501.

[28] Allaire, J. C., McLaughlin, A. C., Trujillo, A., Whitlock, L. A., LaPorte, L., & Gandy, M. (2013). Successful aging through digital games: Socioemotional differences between older adult gamers and non-gamers. *Computers in Human Behavior*, *29*(4), 1302-1306.

[29] Robert, P. H., König, A., Amieva, H., Andrieu, S., Bremond, F., Bullock, R. & Manera, V. (2014). Recommendations for the use of Serious Games in people with Alzheimer's Disease, related disorders and frailty. *Frontiers in aging neuroscience*, *6*.

[30] Eckstein, M. P. (2011). Visual search: A retrospective. *Journal of Vision*, *11*(5), 14.

[31] Whiting†, W. L., Madden, D. J., Pierce, T. W., & Allen, P. A. (2005). Searching from the top down: Ageing and attentional guidance during singleton detection. *The Quarterly Journal of Experimental Psychology Section A*, *58*(1), 72-97.

[32] Faust, M. E., & Balota, D. A. (1997). Inhibition of return and visuospatial attention in healthy older adults and individuals with dementia of the Alzheimer type. *Neuropsychology*, *11*(1), 13.

[33] Wolfe, J. M., O'Neill, P., & Bennett, S. C. (1998). Why are there eccentricity effects in visual search? Visual and attentional hypotheses. *Perception & Psychophysics*, *60*(1), 140-156.

[34] Baddeley, A. (1992). Working memory. *Science*,*255*(5044), 556-559.

[35] Belleville, S., Chertkow, H., & Gauthier, S. (2007). Working memory and control of attention in persons with Alzheimer's disease and mild cognitive impairment. *Neuropsychology*, *21*(4), 458.

[36] Alario, F. X., Costa, A., Ferreira, V. S., & Pickering, M. J. (2006). Architectures, representations and processes of language production. *Language and Cognitive Processes*, *21*(7-8), 777-789.

[37] Barrouillet, P., & Camos, V. (2001). Developmental increase in working memory span: Resource sharing or temporal decay?. *Journal of Memory and Language*, *45*(1), 1-20.

[38] Meguro, K., Shimada, M., Someya, K., Horikawa, A., & Yamadori, A. (2001). Hemispatial visual-searching impairment correlated with decreased contralateral parietal blood flow in Alzheimer disease. *Cognitive and Behavioural Neurology*, *14*(4), 213-218.

[39] Iachini, T., Ruggiero, G., & Ruotolo, F. (2009). The effect of age on egocentric and allocentric spatial frames of reference. *Cognitive processing*, *10*, 222-224.

[40] Carlomagno, S., Lavarone, A., Nolfe, G., Bourene, G., Martin, C., & Deloche, G. (1999). Dyscalculia in the early stages of Alzheimer's disease. *Acta Neurologica Scandinavica*, *99*(3), 166-174.

[41] Moyer, R. S., & Landauer, T. K. (1967). Time required for judgements of numerical inequality.

[42] Gallistel, C. R. & Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition*, *44*(1), 43-74.

[43] Wechsler, D. (1955). Wechsler Adult Intelligence Scale Manual. New York: Psychological Corporation.

[44] Harvey, P. D. (2012). Clinical applications of neuropsychological assessment. *Dialogues in clinical neuroscience*, *14*(1), 91.

[45] Laeng B. (2006) Constructional apraxia after left or right unilateral stroke. Neuropsychologia, 44:1595-606.

[46] Wechsler, D. (1955). WAIS [Manual]Psychological Corporation, San Antonio, TX.

[47] Joy, S., Fein, D., Kaplan, E., & Freedman, M. (2001). Quantifying qualitative features of Block Design performance among healthy older adults. *Archives of clinical neuropsychology, 16(2),* 157-170.

[48] Benton, A. L. (1967). Constructional apraxia and the minor hemisphere. *Confinia Neurologica, 29(1)*, 1-16.

9. APPENDIX

8.1 Appendix 1 - JSON Observations: data structure example


```
{
  "observation":{
    "profile":"stage",
    "data":[
      {
        "profile":"progressive",
        "value":75
      },
      {
        "profile":"game_type",
        "value":"mdc_vnd_ait_game_types_match_it"
      },
      {
        "profile":"match_it",
        "data":[
          {
            "profile":"number_of_card_pairs",
            "value":23
          },
          {
            "profile":"number_of_semantically_related_pairs",
            "value":58
          },
          {
            "profile":"full_board_game_match_it",
            "value":"random_string"
          }
        ]
      },
      {
        "profile":"pause"
      },
      {
        "data":[
          {
            "profile":"position_miss",
            "value":"random_string"
          }
        ],
        "profile":"miss"
      },
      {
        "profile":"skip"
      },
      {
        "profile":"restart"
      },
```

```
      {
        "profile":"quit"
      },
      {
        "data":[
          {
            "profile":"position_target",
            "value":"random_string"
          },
          {
            "profile":"delta_target",
            "value":"random_string"
          }
        ],
        "profile":"target"
      },
      {
        "data":[
          {
            "profile":"position_distractor",
            "value":"random_string"
          },
          {
            "profile":"delta_distractor",
            "value":"random_string"
          }
        ],
        "profile":"distractor"
      },
      {
        "profile":"movement"
      },
      {
        "profile":"selection"
      },
      {
        "profile":"deselection"
      },
      {
        "profile":"rotation"
      }
    ]
  }
}
```


END OF DOCUMENT