A Mobile Memory Game for Patients with Acquired Brain Damage: A Preliminary Usability Study

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Abstract— **Memory rehabilitation and training is an important activity for patients with Acquired Brain Damage, including Cerebral Vascular Accident (stroke) and Traumatic Brain Injury patients. Although many interactive web-based and computer applications have been developed, the use of mobile devices apps has not been sufficiently studied from the point of view of its usability for these users. In this paper, a preliminary usability and accessibility study of a memory game for mobile devices (developed from scratch under Android OS) is presented. This study, based on the Shadow Expert Technique, allows improving the prototype and provides useful hints for increasing acceptability of Android applications, not only by Acquired Brain Damage patients but also by other people with cognitive disorders.**

I. INTRODUCTION

Memory disorders are one of the most common cognitive disorders, as they are associated to prevalent chronic diseases such as Alzheimer, Parkinson, Cerebral Vascular Accident (CVA or Stroke), Traumatic Brain Injury (TBI), etc. [1]. Furthermore, a decline in memory abilities is also associated to less serious conditions like Mild Cognitive Impairment (MCI), or even seen as a result of normal aging (the so-called Age-related Memory Impairment) [2]. Besides this prevalence, their importance lies in the fact that memory difficulties can have a major impact on self-confidence, may increase anxiety and depression, and can make independent living and autonomy very difficult [3]. Therefore, interventions aimed at helping with memory difficulties are valuable not only because of their cognitive effect but also because they may have the potential to improve users' and carers' wellbeing [3].

For this reason, memory aids and training activities are widely used, either as part of the treatments of people suffering from these chronic diseases or simply as a recommendation for a healthy life-style for elderly people [4]. Recently, many of these activities have taken the form of Interactive Computer Applications, of which remarkable examples are Smartbrain [5], Dakim [6], VigorousMind [7] or Lumosity [8]. Most of these applications are web-based and/or designed for desktop use. To the best of our knowledge, the usability of mobile devices by users with cognitive disorders has not been sufficiently studied, despite its importance in improving the usage of these devices [9]. We focus here on an Android application as this OS currently dominates the world smartphone market.

Although some authors argue that the efficacy of cognitive training in improving cognitive functioning is still not demonstrated (higher quality trials are needed) [10], recent results show that there are growing evidences that interactive computer games and activities have positive effects in cognitive functions like memory and focused attention [11][12]. An additional benefit of using computer games (also called *video-games*) for memory training is their ability to increase motivation [13], which is important in typical memory exercises as they may seem repetitive and monotonous for some users. The mechanisms used in video-games to increase motivation are not only extrinsic (like encouraging messages or rewards) but also intrinsic (satisfying fundamental human needs) [14]. For instance, they can satisfy the need for competence (sense of efficacy) provided that the game balances challenges and user's ability to address them. This is particularly important (and difficult) when the targeted users are people suffering from cognitive disorders with different levels of severity. Also, a video-game can satisfy the need for autonomy, allowing to exercise without an instructor or health professional. Additional benefits (for the patients and also for their carers/relatives) include the possibility of using the game as an educational tool to increase knowledge of the disease, or the ability to improve socialization if the game is played together with other patients or friends.

In this paper we describe a memory game that is part of a platform developed in Project PROCUR@, an e-care and e-rehabilitation platform focused on neurodegenerative diseases patients, their carers and health professionals [15]. The project is based on the deployment of three Social Spaces for Research and Innovation (SSRI) [16] in the three validation scenarios: Parkinson's disease SSRI, Alzheimer's disease SSRI, and Stroke (Cerebrovascular Accident) SSRI. It is in this latter SSRI where the game is being developed, although it will eventually be used (with modifications) in the other two SSRIs. The game focuses only on cognitive training (memory and concentration) and therefore physical rehabilitation is not considered.

Instead of defining new rules, problems to solve, etc. we simply decided to adopt the well-known memory card game, for the following reasons:

- To ease its rapid adoption and acceptance by elderly and/or cognitive disorder people, a game should be familiar, straightforward and easy to learn without the

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need of complicated instructions [17]. The intended users may probably have little experience with computers or tablets, so we preferred a classic, simple memory game similar to the board game they may have used before.

- It's relatively easy to personalize the level of difficulty just increasing/decreasing the number of cards or changing the images.

- Usability and Accessibility were two of our main concerns, and this type of games does not require a precise hand/finger control, also allowing audio description of the images, big icons, etc.

With regard to this latter issue, our memory game accomplishes accessibility recommendations about multimodal information provided and sizes and colour styles. To accomplish usability, the 10 usability heuristics [18] proposed by Nielsen and widely used elsewhere have been followed.

II. DESCRIPTION OF THE PROTOTYPE

A first prototype of the memory card game has been developed for the Android platform, more specifically for Android devices with screens of 10.1". With this choice we try to optimize the viewing area as many of the target users may have some visual impairments. In the next paragraphs the design of the application is described, as well as the architecture of the implemented prototype.

A. Prototype design

Although the memory card game is widely known, the rules are briefly described below:

- The goal of the game is to find out pairs of matching cards (for instance, those with the same picture). At the beginning, all the cards are facedown.

- The user starts by clicking one card, turning it face-up. Then, he/she selects another one.

- In case the cards do not match, the selected cards are put facedown after a small time period. On the contrary, if the cards match they make a pair and both cards are removed.

- The user continues discovering the rest of pairs until all the cards of the screen have been removed.

The first version prototype responds to a user-centred design. In order to meet this target, a multimodal interface has been developed, with additional features to improve usability and accessibility for users with cognitive disorders, including:

- Landscape layout format.

- The action of selecting a card has two feedback methods: (i) haptic feedback; (ii) audio feedback, i.e., a descriptive voice message about the object is played-back.

- In case of not matching cards, both cards are kept face-up for a variable period of time before putting them face-down, depending on the cognitive disorder of the user.

- Moreover, when a pair of cards is discovered, reinforcement mechanisms are used: (i) both cards are animated (enlarged); (ii) a motivational message is synthesized to encourage the user to keep playing.

- Motivational messages are also reproduced when the user advances to the following level.

Fig. 1 shows a snapshot of the prototype interface; just at the moment when the user finds a pair of matching cards.

B. Architecture

In this section, a brief description of the classes used in the first version of the prototype is presented:

- *Class MainActivity:* this is the main class (activity in Android), the view controller of the screen. The class gets an xml template that describes the layout of the screen and allows the dynamic loading of cards by means of the methods provided by the classes "Card" and "Board". Also, it keeps track of the time spent from the start of the game to the end of a difficulty level.

Figure 1.   Screenshot of a matching pair cards with enlargement effect

- *Class Card:* it encapsulates all the associated information of a card.

- *Class Board*: it encapsulates the association between position of a card and its image. Therefore, the *MainActivity* class delegates the control of images and cards to this class.

- *Class Speaker:* It uses the class *TextToSpeech* [19], supplied by Android, to generate audio speech from text.

III. EXPERIMENTATION

As mentioned in the Introduction, accessibility and usability are two of the main requirements in this project. Although they were taken into account in the design phase, the prototype needed to be tested with users to obtain a first feedback about its usability, accessibility and user-experience.

In this paper, the Shadow Expert Technique (SET) [20] was used over two groups of users with different profiles to obtain a wide range of feedback information. SET is a usability testing technique focused on obtaining information during user interaction with the prototype, attending not only to aspects such as accessibility and usability, but also users' emotions –satisfaction or frustration–.

SET is divided into three stages [20]: (i) Preparation; (ii) Test and structured discussion and (iii) Analysis.

A. Preparation

In the Preparation phase a stable version of the prototype was used (and kept unchanged during all the experiments) and users were selected. The users were divided into two groups: a first group with experts in neurorehabilitation who use to work with cognitive disorder patients (CVA and TBI); and a second group with the patients themselves with different cognitive limitations. The neurorehabilitation professionals provided important information about therapeutic improvements of the game and how to make it easier from the patients' point of view. Patients were selected with different cognitive disorders and ages, as seen in table I.

TABLE I. PARTICIPATING USERS. P=PATIENT, T=THERAPIST

Id	Age	Sex	Level of cognitive deterioration	Educational level
P1	70-80	M	High	Low
P2	30-40	M	Medium	Medium
P3	30-40	M	Low	High
T1	30-40	F	Null	High
T2	40-50	F	Null	High
T3	40-50	F	Null	High

Additionally, in this phase usability experts were selected. Four usability experts acted as observers and also an additional expert in e-health development contributed with his knowledge about cognitive disorder patients.

B. Test and structured discussion

In the Test and structured discussion phase, users interact one after another with the prototype while usability experts are present. Users were asked to use the so-called "Thinking Aloud Method" [20] so they were encouraged to speak verbally during the interaction to express any thought, any doubt, and any feeling. All this information is logged by the usability experts while the rest acted as observers. The identification of important non-verbal emotional information is supported in SET through the mirror neurons theory.

TABLE II. USABILITY BARRIERS IDENTIFIED BY THE PATIENTS

Barrier	Number of patients finding the barrier
Modal dialog to "continue playing" is confusing	3
Accidentally touching areas of the screen	1
Touching more than once a card leads to an exception in use cases.	1
More than eight cards seems to be confusing	1
"Exit game" button location is confusing	1
"Exit game" modal dialog is confusing	3

During the tests several barriers where identified by users as shown in table II. The neurorehabilitation professionals provided some advices to improve game usability, which are collected in table III.

TABLE III. RECOMMENDATIONS OF THERAPISTS

Recommendations of neurorehabilitation experts	Coincidence
Cards should be hidden automatically	1
Exit button must be reconsidered	3
Finger sliding to change difficulty level can be confusing for patients	2
The equivalent board memory game establishes a more coupled relationship with users. Conclusion: automatic actions should be substituted by manual user actions.	1
Audio instructions would be necessary to help users to play without assistance	1
Limit the max. number of cards. Use different strategies to increase difficulty.	1

During the structured discussion, one of the experts acted as facilitator, being responsible of acting as moderator of the dialogue. The discussion was limited in time to avoid digressions.

The changes for the next game versions approved during the structured discussion are detailed below:

1. Fork versions to evaluate the usability of two options: turning cards over either automatically or manually.

2. Exit button must always be visible and accessible. Modals must be avoided.

3. The first prototype allowed changing the difficulty level by sliding the finger across the screen ("swipe gesture"). This gesture should be avoided.

4. Modal that asks whether or not the user wants to keep playing must be removed.

5. Never more than two cards should be face-up.

6. Tap gesture must be added as a way to turn a card over. This makes screen more sensible, and therefore more accessible in case of motor impairments.

7. Clicking the same card more than once should be disregarded as it may be due to an imprecise hand/finger control (e.g. tremor).

8. Voice messages encouraging users to continue playing should be added.

9. The first prototype included voice messages informing users about the time passed and points obtained, but this information may be confusing and should be removed.

10. The max. number of cards should be limited to 8 or 10.

11. Several options for voice help messages should be tested with users in three fork versions of the game

    A. Reproduced only when a user starts the game.

    B. Repeated after an inactivity period.

    C. Include an interface element that allows users to manually reproduce the messages.

12. It should be possible to disable voice help messages when the user is playing with assistance.

13. The complexity or difficulty of the game can be managed by grouping semantically different cards into different levels of difficulty. For instance, a first level

could be made of pairs of simple, every-day objects. Higher difficulty levels could be made of pairs of abstract figures not too different to each other; pairs of objects and their written names; pairs of simple arithmetic operations and their results; etc.

C. Analysis

As a result of the tests described before, the following usability issues have been discovered, related to the Android standard components included in the application:

- *Modal dialog boxes*: In most cases, there is no action from the user when a dialog box is shown to request confirmation about continuing playing or quitting the application.

- *Notification messages* (*Toast*), a non-interactive component that provides feedback in a small popup, without blocking the application, and disappearing after a timeout. Contrarily to its intended purpose, the user tried to select the Toast message by a single tap.

- *Swipe gesture*, commonly used in Android to allow the user to efficiently navigate between views corresponding to consecutive levels: Almost no user tried to employ any movement-based gestures (such as swiping).

- *Back* button, also commonly used as a way to stop and restart an activity: Similarly to the previous case no user was able to quit the application by clicking back button.

Note that these usability issues are not specific of our application, so they could be considered as general potential problems for the use of Android-based applications by this kind of patients. Therefore, taking into account these interaction problems the application has been modified as follows:

- Dialogs, notification messages (*Toast*) and *Swipe gesture*, have been removed.

- A specific image to quit the application has been added.

In addition, according to therapists' suggestions, instructions about the game have been included. These instructions are reproduced at the beginning of the game by clicking an image. Furthermore, after one minute elapsed without any kind of interaction, a message to remember how to reproduce again the instructions is synthetized. This message is visually reinforced with an enlargement animation that is applied on the image that executes the complete help.

IV. CONCLUSION

In this paper, an Android memory game specifically designed for patients with Acquired Brain Damage (ABD) has been described. Its design has followed a user-centered approach, and a first prototype has been tested for usability, accessibility and user-experience following the Shadow Expert Technique (SET).

Two groups of users participated in the trials: three neuro-rehabilitation therapists and three ABD patients. Additionally, a number of usability and e-health experts acted as observers contributing with several suggestions.

As a result, several usability and accessibility flaws have been identified and corrected in the prototype. Furthermore, some issues regarding usability of generic Android applications are presented in the paper, particularly useful if they are to be used by ABD patients.

Future work will include experiments with a larger user group to assess the usefulness of this game, as well as its usability as compared with other commercially available similar applications.

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