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Development of an Interactive Artifact for Cognitive Rehabilitation based on Augmented Reality

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***Abstract*—Cognitive rehabilitation, which uses software applications (multimedia), advanced physical devices (PDAs, cellular phones, etc.) or virtual reality applications, presents limitations of several types related to: workspace, realistic representation, intuitive interaction, dexterity demand, availability, devices dependency, user-friendly interface, customization, multi-sensory input/output, complexity, etc. Recently, the technological evolution has allowed the development of artifacts based on augmented reality that overcome most of the weaknesses of the applications implemented with the previous technology. In this way, this paper presents and discusses the development of an interactive artifact based on augmented reality, which makes possible intuitive tangible interactions, multi-sensory feedback, customization, simplicity and the implementation of cognitive exercises. Ten users evaluated cognitive applications running over the interactive artifact under the point-of-view of augmented reality, giving their impressions. Finally, we discuss the potential of the interactive artifact, pointing out directions to improve its structure and utilization by cognitive disabled people.**

Cognitive rehabilitation; augmented reality; interactive artifact; tangible interactions, customization

I. INTRODUCTION

Humans actuating in the physical world frequently use artifacts as extension of their own knowledge and reasoning systems to help remembering and processing information [1, 2]. Classical examples are shopping lists and a string tied around a finger. In this way, artifacts, which are used in cognitive applications, are named cognitive artifacts.

The term "cognitive artifacts" was coined by Norman [3] and has several definitions, depending on the available technology and the application area. An up-to-date general definition of cognitive artifact is a physical object or software application used to aid, enhance or improve thinking and reasoning.

Nowadays, with the technological evolution, cognitive rehabilitation is using interactive artifacts, including software applications (multimedia and virtual reality) and physical objects controlled by computer (PDAs, cellular phones, specific devices with GPS, accelerometers and other technological resources, etc.). Those artifacts are part of technology for cognitive rehabilitation and can help disabled people presenting traumatic brain injury, cerebrovascular accident, learning disabilities and multiple sclerosis. Besides, they have some potential to aid people with dementia, autism spectrum disorders and mental retardation [4].

Some of those artifacts are useful for retraining (restoring cognitive functions) or for cognitive skills development. Other artifacts, named cognitive orthoses or cognitive prosthetics, use compensatory strategies that modify the patient's environment with context-sensitive cognitive support to improve their personnel skills [4].

The cognitive artifacts used for retraining and cognitive skills development can explore the following skills: temporal and spatial orientation; attention, concentration and calculation; language understanding and speaking; understanding of social cues; judgment and abstraction; immediate recall, recent memory and remote memory; organization; planning and problem solving; mental processing speed; multi-sensory processing (visual, auditory and motor); self control and self confidence.

Practicing those skills, cognitive disabled people can restore or improve their cognitive functions, such as: understanding and following instructions, selecting and evaluating things, reasoning, making decisions, constructing and describing things, etc.

However, cognitive disabled people often also have physical and sensory limitations that need to be considered and overcame in the design of a cognitive artifact. Those limitations involve vision, hearing, tactile sense, fine motor control, speech and coordination [4].

With recent technological trends, rehabilitation patients are getting access to advanced interactive devices with interesting features, such as highly technological, highly interactive and multi-sensory. Nevertheless, those devices present weaknesses including: complex using, difficulty to convert the rehabilitation training to real-life benefits, low or medium availability, medium or high cost, medium or high dexterity demanding, etc. To overcome such problems, the key is the use of assistive devices presenting simplicity as their main feature [5].

This paper presents the development of an interactive cognitive artifact for retraining and improvement of cognitive skills, aiming at satisfying the main characteristics wanted in a modern cognitive device, such as: low cost, easy customization, user-friendly interface, multi-sensory input/output, low dexterity demanding, etc. The paper also shows how we intend to supply highly technological applications in a simple and transparent way to cognitive disabled people and therapists.

II. Related Work

Interactive cognitive artifacts [6] are related to software applications or physical objects controlled by computer.

Software applications involve multimedia and virtual reality environments and are used to accomplish cognitive rehabilitation exercises.

Multimedia software applications for cognitive rehabilitation are freely and commercially distributed, involving memory, logic, attention, perception and motor control [7, 8, 9]. Although multimedia applications are plenty of multi-sensory elements, they have limitations in representation, realism and interaction.

Virtual reality systems could overcome multimedia limitations, presenting strengths, such as three-dimensional representation, more realism and intuitive interaction. However, they present user inability to touch virtual objects, side effects and the necessity of non-conventional input/output devices such as: gloves, head mounted displays, stereoscopic displays, trackers, etc. [10. 11]. To overcome the user inability to touch virtual objects, haptic technology was introduced into virtual reality rehabilitation systems to generate force feedback to patients while they perform their exercises. Research has been done on virtual reality cognitive rehabilitation involving training and assessment of logic, attention, perception and motor control [12, 13, 14].

On the other hand, physical objects controlled by computer present strengths such as intuitive tangible operations and complete presence sense, but have limitations related to dexterity demanding and spatial reaching. Some physical objects controlled by computer can be found as smart professional devices, such as smart phones, PDAs, videogames, etc. These devices present potential for cognitive rehabilitation, mainly as games [15, 16], but have access and customization limitations. Other interactive artifacts available as prototypes can be used alone or integrated in a physical environment.

Interactive physical artifacts have been studied and developed in several areas, such as: ambient intelligence [17], disappearing computing environments [18, 19] and ubiquitous or pervasive computing applications [20, 21]. The interactive artifacts can use different technologies to implement new features in a physical object, such as embedded electronic sensors and actuators [22], RFID [23], wireless communication [17], touch screen [24], computer vision [25, 26], etc. Those technological enriched physical objects, when used for cognitive rehabilitation, are known as cognitive artifacts. Cognitive artifacts usually present significant potential to be implemented with augmented reality based on computer vision, once the prototype can present low cost and be easily distributed. Interactive artifacts for rehabilitation are being developed, but most of them are applied in motor rehabilitation. There are few examples related to cognitive rehabilitation [25, 27, 28].

Our research differs from other ones mentioned in this paper, since the development of our cognitive artifact pursuit simplicity in almost all aspects, such as design, implementation, interaction, customization, user interface and application.

III. Development of the Artifact-AR

Artifact-AR is a cognitive artifact based on augmented reality technology that fulfills the following requirements:

a) The artifact must have cognitive potential, involving multisensory perception, memory, attention, logic and motor control in order to allow the preparation of cognitive exercises.

b) The physical parts of the artifact must be made with ordinary materials and process, presenting availability and low cost.

c) The logical parts of the artifact must use augmented reality technology based on computer vision software.

d) The interactive actions to be executed on the artifact must be tangible and easy.

e) The cognitive exercises prepared with the artifact must be simple and easily customized by therapists.

f) The user interface implemented on the artifact must consider usability (ease of understanding, ease of learning and ease of use), human factors (usable, effective and accepted by users) and ergonomics (safe and efficient).

A. *Implementation of the Artifact-AR*

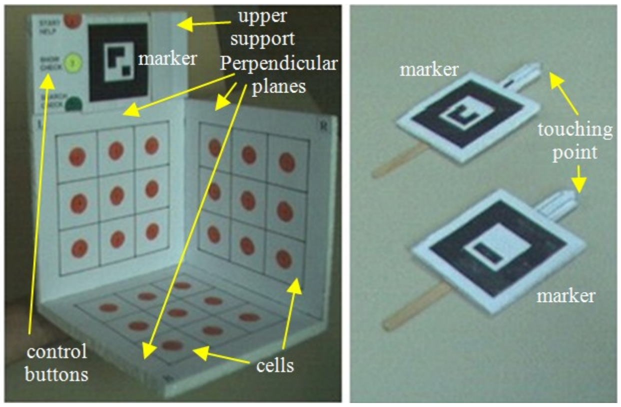
In order to implement the Artifact-AR satisfying those requirements, we made the following decisions:

a) Using a three-dimensional structure that allows the implementation of cognitive exercises involving: identification, memorization, comparison and association of patterns and sequences of visual and auditory information. We choose a structure with three perpendicular planes and an upper part to show auxiliary elements, such as: support for augmented reality markers, buttons for user interface and displaying area for cognitive work, according Fig. 1a. The three perpendicular planes must contain buttons that allow the assembly of patterns based on individual cells.

b) Using Styrofoam (EPS), cardboard or wood to implement the physical structure tied with glue, following instructions and templates to be available on the Internet.

c) Using an augmented reality tool for rapid prototyping based on ARToolKit [29] that uses computer vision and image processing simple algorithms to recognize markers (square frames with icons inside them).

d) Using few physical pointers with coupled markers that can be tracked by the augmented reality system in order to allow touching user interface buttons (Fig. 1b).



a) Physical artifact structure b) Physical pointers with markers

Figure 1. Structure of the physical artifact and its pointers.

e) Implementing simple cognitive exercises, actuating alone or integrated, including identification, memorization, comparison and association of patterns and sequences of pictures, shapes, colors, characters and sounds. Those exercises are expanded adaptations of multimedia cognitive exercises usually offered as computer programs or Internet applications.

f) Considering usability, human factors and ergonomics applied to augmented reality user interfaces, such as using colors to show activated and deactivated buttons, using layers to overlap pictures and instructional information according priorities, arranging buttons to make easy interaction with augmented reality pointing devices, using sounds and narrations to help identifying actions and giving instructions and information to users, using markers to change cognitive applications.

The Artifact-AR was implemented as a three-dimensional structure built with three perpendicular planes, so that each one contains nine cells that can be virtually colored or has spatial colored virtual "coins" activated (Fig. 2).

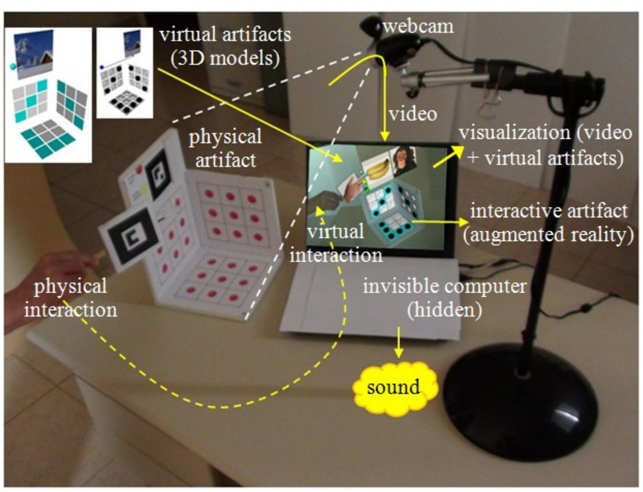


Figure 2. Augmented reality environment used to implement the Artifact-AR.

Besides, on the upper side, there is a plane extension used to accommodate the application marker and control buttons and to receive visual information like pictures and texts. The user interacts with the physical artifact, hears the auditory information from computer loudspeaker and visualizes effects (video of the physical artifact expanded with virtual information) on a monitor placed in front of him/her.

The visualization can also be done with a projector or an augmented reality head mounted display, but using a computer monitor is cheap, available and easy to operate. The artifact allows direct interaction with sound feedback, but the visualization will be indirect when a monitor or a projector is used, or direct when a head mounted display is used.

B. *Customization of the Artifact-AR Applications*

The augmented reality tool ARAS-NP [30] used to implement the Artifact-AR does not need programming knowledge. Hence, therapists can easily customize cognitive applications, aiming at personalize them to each patient. In order to make easier the customization of the application, the system was structured in several layers, according to Fig. 3.

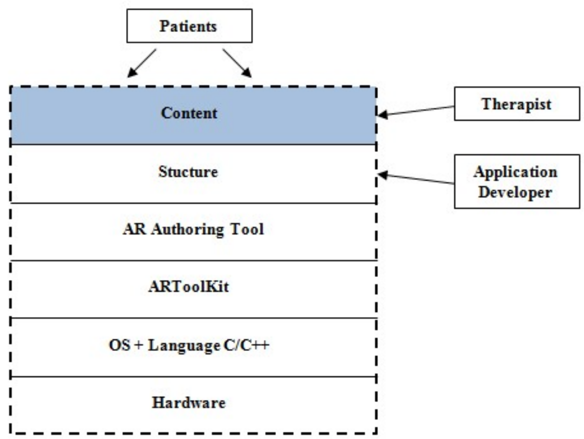


Figure 3. Layers of the artifact application.

Considering the upper layers, the structure will be manipulated by the artifact developer and content will be filled by the therapist to create or change images and sounds. To realize customization, the therapist must access some folders in order to change, pictures, sounds and colors (Fig. 4). The therapist can use a text editor, like notepad for example, to edit the files contained in the folders.

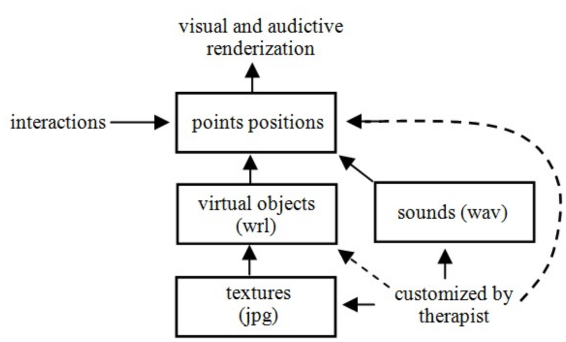


Figure 4. Folders that can be adjusted by therapist.

To change the textures, the therapist can prepare new ones, delete the non-wanted textures from the "texture" folder and place there the new ones renaming them with the same names.

To change the sounds, the therapist can use the same procedure related with textures, manipulating sounds and using the audio folder. To change color patterns, the therapist can pick up pre-built patterns (virtual object) from a library, delete the non-wanted patterns from the virtual objects folder and place there the new ones renaming them with the same names. In this case, as each virtual object also has a texture link, it will be necessary to rename the texture file related to it.

Moreover, the therapist, who is familiar with computing resources, can edit folders and files. In this case, the therapist can change a pattern (virtual object) editing the color of the cells, according to Fig. 5a. To change pictures, the therapist can place a new picture in the "texture" folder and edit the "wrl" file, changing the texture name (Fig. 5b). To change the sound, the therapist can place a new one in the "audio" folder and edit the "dat" file contained in the "wrl" folder, changing its name (Fig. 5c).

```
...
    DEF center-right Shape {
     appearance Appearance {
      material USE Cyan
     }
...
```

a) Changing cell color (edit virtual object.wrl)

```
...
    texture ImageTexture {
     url [
      "textures/text-1.jpg"
     ]
    }
...
```

b) Changing texture (edit virtual object.wrl)

```
wrl/grid3d/grid3d-t1.wrl
60.0 -150.0 5.0          # Translation
0.0 0.0 0.0 1.0          # Rotation
10 10 10                 # Scale
audio/pause              # audio file
0 0
```

c) Changing sound (edit virtual object.dat)

Figure 5. Customization of Artifact-AR applications by therapist.

It is also possible to create new virtual objects with colors, textures and sounds, placing new pictures and sounds in the corresponding folders, editing the "wrl" files and saving them using new names and editing the corresponding "dat" files inserting the new information into them. Alternatively, if the therapist has expertise to work with graphical editors, he/she can easily edit color, textures and shapes, opening the files in a graphical editor. However, each "dat" file needs to be edited with a text editor.

With the process mentioned here, a therapist can expand or personalize an Artifact-AR application.

IV. USE OF THE ARTIFACT-AR

We initially developed two cognitive applications exploring identification, memorization, comparison and association of pictures, patterns and sounds. An application considers pre-built patterns whereas the other one allows the assembly of patterns through the interaction with the cells individually.

To operate the applications, it is necessary to use two interaction pointers and three control buttons (Fig. 6). The interaction with the marker "I" serves to activate and deactivate pictures, patterns and sounds. The interaction pointer with the marker "C" is used to show a new picture and/or pattern, playing sound. The visualization showed on the Fig. 6 was done on a computer monitor.

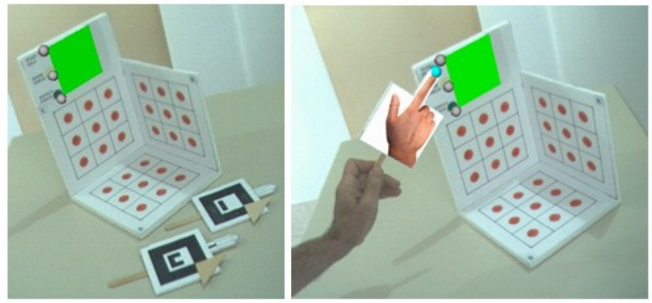


Figure 6. Interaction pointers and control buttons.

If the user is not familiar with the Artifact-AR, he/she can see and hear instructions about the device and the application, touching the red button (start/help) with the interaction pointer with the marker "I". On the upper auxiliary plane, the user will see the first instruction page. To continue reading and hearing the next pages, the user needs to touch the same button with the interaction pointer with the marker "C" (Fig. 7). The other control buttons also have a first page showing instructions.

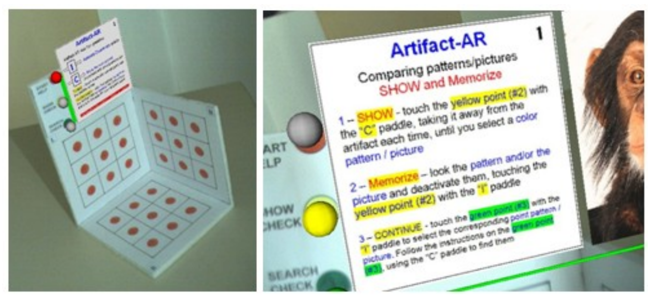


Figure 7. Artifact-AR showing help information.

A. *Using the artifact version with pre-built patterns*

This version of the Artifact-AR can show pre-built patterns on the three perpendicular planes and pictures on the two upper planes (one is real and other is virtual) and play sounds during the displaying of pictures and patterns (Fig. 8). To make comparison and association of pictures and sounds, it is enough to show a picture on the left upper plane and the other on the right upper plane, playing their corresponding sounds if they are wanted. The therapist can disable pictures or sounds to explore them individually.

On the perpendicular planes, two types of patterns can be shown: the first one is based on flat colored cells and the other one is based on virtual colored embossed "coins". As the two types of patterns shared the same space, it was necessary to place one pattern on the cell (square and flat) and the other overlapping the cell (round and embossed). In this way, it is possible to see both pattern types in a cell at the same time and make comparisons and associations.

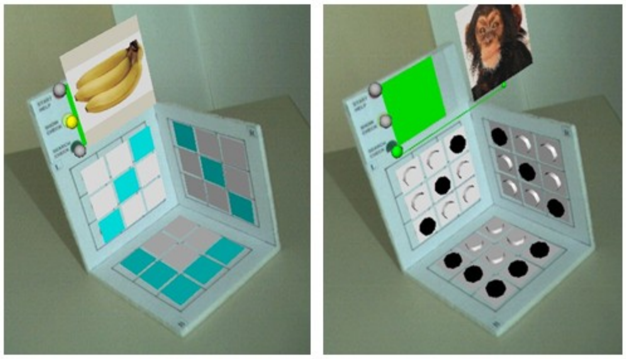


Figure 8. Pictures and patterns on the Artifact-AR.

In this artifact version, the red button (start/help) serves to show and narrate operation instructions when the application is started or when the user needs help. The yellow button (show/check) serves to show pictures on the left side and/or color patterns on the perpendicular planes. The green button (search/check) serves to show pictures on the right side and/or virtual embossed colored "coins" on the perpendicular planes.

To make comparison or association involving pictures and/or patterns, the user must activate the picture on the left side and/or the flat color patterns on the perpendicular planes first, touching the interaction pointer with the marker "I" on the yellow button (show/check). After that, touching several times the same button with the interaction pointer with the marker "C", the user can change pictures and/or patterns until select a picture and/or pattern. Doing the same thing on the green button (search/check), the user can select a picture on the right side and/or a pattern composed of virtual embossed "coins" on the perpendicular planes, comparing or associating pictures and/or patterns (Fig. 9). Besides, the user can compare or associate sounds with pictures and/or patterns. Using the interaction pointer with the marker "I", the user can hide/show a picture and/or pattern and play the corresponding sound, creating memorization applications.

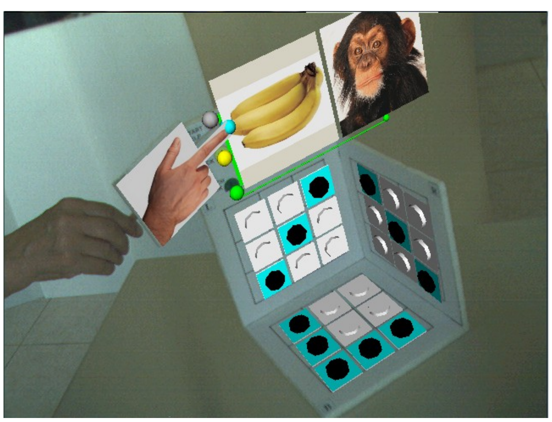


Figure 9. Checking pictures and patterns.

To ease the identification of buttons status, their colors change when they are activated and deactivated.

B. Using the artifact version with pattern assembled by users

In this version, the user can select a flat color pattern using the yellow button (show/check) and assemble his/her own pattern activating individual cells, showing virtual embossed "coins" (Fig. 10).

Figure 10. Using virtual embossed "coins" individually.

Besides, it is possible to change color "coins", using the interaction pointer with marker "C" touching an activated cell. Sounds and pictures can be used too. Other possibility is to show pictures containing one plane pattern in order to serve as reference to be replicated by the user through the activation of cells on a plane (Fig. 11).

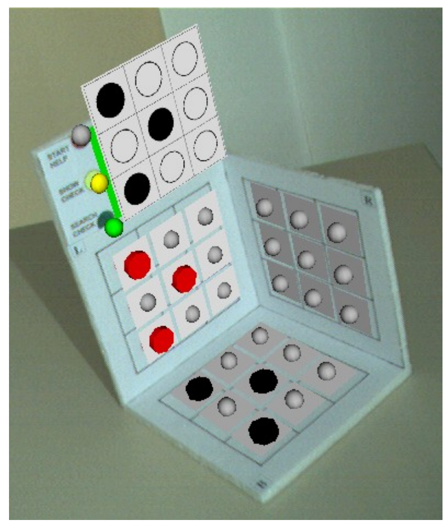


Figure 11. Showing reference pattern as picture.

It is also possible to have a fourth control button to activating rewards, playing animations and sounds depending on the therapist.

C. Evaluation of the applications

The Artifact-AR applications were evaluated considering aspects of augmented reality usability [Kaufmann 2007]. Ten potential therapists have tested the Artifact-AR, playing the two versions of the cognitive exercises. The users followed the narrated and written instructions and solved the proposed exercises under de supervision of an augmented reality expert.

Before testing, the users were exposed to demonstrations and, after testing, they filled a questionnaire, responding to 12 questions about augmented reality aspects of the Artifact-AR applications (Table 1). For each question, they choose one from five options (5 – excellent, 4 – very good, 3 – satisfactory, 2 – fair, 1 – poor), according Likert scale. The 12 questions were collected into four groups of usability factors (three questions for each group) evaluating the application, interface, visual aspects and auditory aspects.

TABLE I. AUGMENTED REALITY ASPECTS OF THE ARTIFACT-AR

Usability Factors	Analyzed items
(a) Interaction with the Artifact-AR	(1) Pointers handling. (2) Pointers collision with buttons and cells. (3) Response time of the interaction.
(b) Artifact-AR Interface	(4) Easiness, learnability and usability. (5) Attractiveness. (6) Buttons and pictures positions.
(c) Visual Aspects	(7) Visibility of the physical artifact (buttons and cells). (8) Visibility of the video elements (pictures, texts, patterns, buttons and cells). (9) Visual feedback of the interactions (changing buttons colors, pictures and patterns).
(d) Auditory Aspects	(10) Narration clearness. (11) Auditory feedback of the interactions (activation and deactivation). (12) Sound operation (start, stop, cutting).

The results of the evaluation can be seen in Fig. 12 and Fig. 13. The best results were obtained by analyzed items 3, 5, 7 and 11 with rates between "very good" and "excellent" (Fig. 12).

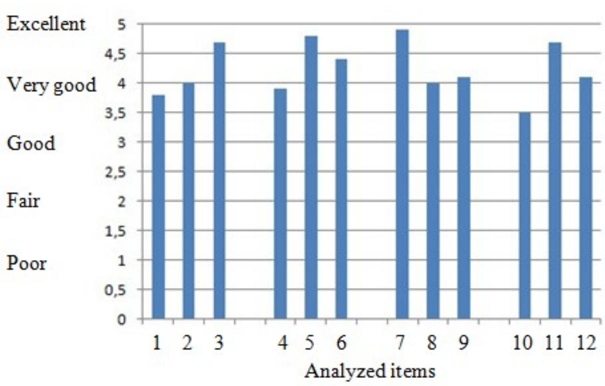


Figure 12. Evaluation of the Artifact-AR (see Table I).

The worst results came from items 1, 4 and 10 with rates between "good" and "very good". The average rate produced by all items exceeds "very good". The maximum standard deviation came from item 2 with the value 0.63 and the minimum came from items 7 and 12 with the value 0.3.

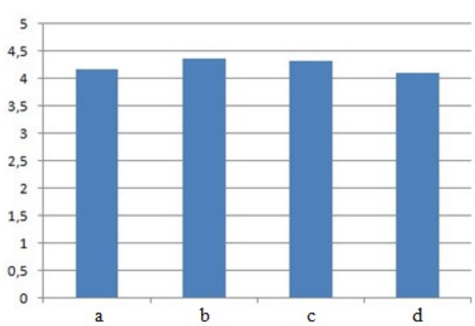


Figure 13. Evaluation of usability factors of the Artifact-AR (see Table I).

Considering the usability factors (Fig. 13), the best results were found on interface and visual aspects and the worst results were produced by auditory aspects and interaction with rates exceeding "very good".

Some external factors have influenced the behavior of cognitive applications with the Artifact-AR, including the environmental factors (illumination, webcam quality, monitor position and quality of computer loudspeaker), user skills with augmented reality technology (webcam awareness, soft movements, pointers visual reentrance) and unfamiliarity with cognitive applications. We believe that cognitive applications with the Artifact-AR can be improved with better resources and familiarity of users with three-dimensional applications.

V. CONCLUSIONS

We presented and discussed the development of an interactive artifact for cognitive rehabilitation based on augmented reality, showing its requirements and the decisions made to obtain strengths, such as: innovative device, user-friendly interface, customizable application and low-cost.

The Artifact-AR was obtained by overlapping a physical artifact video with a corresponding three-dimensional model, allowing interactions based on the physical artifact, visualization of the results in a monitor and hearing the corresponding sounds from a computer loudspeaker.

Although the Artifact-AR presents several strengths, there are some weaknesses that need to be overcome, including dependency of the following elements: webcam quality, adequate illumination, webcam viewpoint and indirect vision and interaction. The webcam quality problem can be solved with the technology evolution, which will provide better devices; the illumination problem can be solved with a controlled environment and better webcams with expanded illumination spectrum; the webcam viewpoint problem, requiring certain marker positions and orientation to work, can be solved with the use of multiple webcams placed at different positions; the indirect vision/interaction problem, depending on a monitor to visualize the Artifact-AR, can be solved with a video-glasses and a webcam placed on the user head pointed to the Artifact-AR or with an augmented reality head mounted display; the quality of the computer loudspeaker can be solved with the use of external loudspeakers.

There are alternative ways to implement the Artifact-AR, such as touch-screen and embedded electronics, but those solutions create device dependency and costs affecting the availability.

Even with the Artifact-AR weaknesses, it seems to be a very interesting option to be applied in cognitive rehabilitation, once the evaluation tests confirmed its strengths related to low cost, availability, user-friendly interface, multi-sensory aspects, tangible interaction, non-demanding dexterity, etc.

Using additional resources of the authoring tool ARAS-NP, it is possible to create new structures and new ways to explore the Artifact-AR, including the use of more interaction pointers to change the environment by deleting, copying and moving pictures and three-dimensional objects, the use of a network shared environment implementing telerehabilitation and the use of trackable path to drive movements.

New Artifact-AR physical structures can be developed to explore other ways to work with pictures and patterns. Using cells with shapes and positions similar to seven segments, it is possible to develop exercises, exploring character patterns, for example.

The Artifact-AR design templates, software, tutorials, videos and cognitive applications will be available for free on the Internet [32] in the next months.

Finally, we believe that the Artifact-AR has high potential to be applied in motor rehabilitation and educational applications due to its three-dimensional features.

Acknowledgment

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