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RehbBrain: A Serious Gaming Platform for Perceptual and Cognitive Rehabilitation

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ABSTRACT

Stroke sequelae significantly affect the individual's functionality, namely at the level of their perceptive and cognitive skills. Consequently, these patients require rehabilitation therapies that are adapted to their dysfunctions. Conventional approaches (traditional board and paper games) have the disadvantage of not being suited to the dysfunctions of some patients, making the rehabilitation process unstimulating and demotivating. RehbBrain is a serious gaming platform, adapted for all patients whose rehabilitation process focuses on stimulating, visually, perceptual and cognitive skills. It simulates the individual's daily activities, in various environments, and with progressive levels of difficulty. The platform aims to help therapists monitor their patients by promoting a systematized and standardized assessment. The games on the platform are intended to complement conventional rehabilitation methods, and render therapy sessions more dynamic, leading to a faster and more patient-oriented stimulation process. RehbBrain's usability was tested by 5 specialists and 33 subjects with no associated pathologies. They completed separate System Usability Scale (SUS) questionnaire to assess the platform, but reached and combined average score of 88.4, classifying RehbBrain as "Excellent".

Keywords: Stroke, Rehabilitation, Occupational therapy, Cognitive skills, Serious games

INTRODUCTION

Stroke is one of the main causes of permanent disabilities in the Western world (Poungvarin, 1998) and the leading cause of death in Portugal (SPAVC, November 2021). Moreover, in comparison with other Western European countries, Portugal has the highest mortality rate from stroke (Correia et al., 2004). This is a disease that affects the brain in a severe and sudden manner, caused by blood blockage (ischaemic stroke) or rupture of a cerebral artery (hemorrhagic stroke), and may lead to critical complications for the patient

(Gomes and Wachsman, 2013). In Portugal, 30% of all strokes lead to the direct death of the individual, whereas 40% of the remaining are left with highly incapacitating sequelae (SPAVC, November 2021), severely impairing the individual's ability to cope with daily routines. Rapid response and treatment, during the first hours, are critical to reduce the number and severity of permanent sequelae and increasing the chances of optimal recovery (Belagaje, 2017).

Stroke sequelae are not only motor, in nature, they also include behavioral or sensory system impairments, which are largely cognitive and perceptual. The former includes slowing mental processes, difficulty in concentrating, memory loss, aphasia, and difficulty in planning, monitoring, and performing tasks (SPAVC, November 2021; NeuroSer, November 2021). Perceptual skills may also be affected, with a decrease in the ability to process sensory stimuli, making the patient unable to distinguish certain characteristics of objects, such as their depth, size, spatial orientation, or assess how far away they are from an obstacle (NeuroSer, November 2021). It is estimated that approximately 50% of all stroke patients will require some form of rehabilitation to help them reach their pre-stroke functional level (Pinter and Brainin, 2012). Several studies confirm the importance of rehabilitation programs to help patients adapt as much as possible to life after stroke. These programs enable the recovery of lost functional skills and the development of new competencies, which will allow patients to lead an independent life.

It is important that rehabilitation is monitored by multidisciplinary teams, specialized in providing care to stroke patients, with health specialists, such as nurses, physiotherapists, occupational therapists, speech therapists, social workers, and other care providers (SPAVC, November 2021; NeuroSer, November 2021). Yet, in most countries, only a small percentage of all stroke rehabilitation units include the complete set of required valences mentioned above. As an illustrative example, from the 28 units, distributed throughout Portugal, only 6 comprise complete rehabilitation teams, as mentioned above (Público, November 2021).

Regarding the rehabilitation methodologies adopted in stroke units, the vast majority is inadequate to fit the specific dysfunction needs of a specific patient. Conventional cognitive and perceptual rehabilitation therapies are mainly based on traditional board games, paper games and mathematical problems (Faria et al., 2016). The cognitive dysfunction of one patient depends on the characteristics of the originating lesion. Hence, generic methods are not applicable and may render the rehabilitation process unmotivating and time consuming (Elaklouk, Zin and Shapii, 2015). With advances in Information and Communication Technologies (ICT), new methodologies are proposed that allow for a greater amount of adaptation and personalization to each patient. They include serious gaming and Virtual Reality (VR) in the set of possible therapy approaches (Faria et al., 2016; Gamito et al., 2017).

The current manuscript describes a set of improvements and extensions proposed to RehbBrain, a serious gaming platform for personalized stroke rehabilitation. The complete work was developed in co-creation with therapists of the Occupational Therapy service of the Hospital Curry Cabral

(HCC). The platform is mainly directed to stroke patients but can be adapted to the rehabilitation of any patient with cognitive and perceptual impairments. RehbBrain arose from the need to help therapists keep records of their patients' progress, providing the possibility for future analyses and drawing conclusions about the patient's evolution in a standardized way. It has then evolved to include a growing set of personalized rehabilitation games.

PRESENTING THE REHBBRAIN PLATFORM

The platform was built in Django[1], which is written in Python. To construct the platform pages, a set of templates were created in HTML, where JavaScript can be used to include a level of dynamics to certain functionalities. RehbBrain was then made available online via Heroku[2], a platform that allows developers to deploy, run and manage web applications entirely in the cloud.

RehbBrain presents different interfaces and functionalities, whether the user is an administrator or a therapist. The latter sees a home page with access links to all stakeholders' websites, with the ability to add new patients, view their therapy history, and the list of available games. Admins can access two extra pages, displaying the list of all patients, of all therapists using the platform, as well as the history of all patients' game interactions.

The platform has currently four therapeutic games, with 10 or 12 levels of complexity each. Two games correspond to oral and bath "hygiene", one deals with "kitchen items", and another with "visuospatial organization". The ones dealing with hygiene and cooking activities demand patients to select images according to a set of instructions, or to identify the correct order of events in a complex task. The visuospatial organization theme consists of organizing objects on a grid, according to their characteristics of shape, color, or orientation in space, in relation to other objects. Two examples of the proposed games are illustrated in the following sections.

The platform records the time, in seconds, required to fulfill the proposed task; the score attained, which depends on the type and level of the game played; the number of moves; the images submitted, together with the order proposed; and all the images selected, in addition to the ones that were submitted. Additionally, the platform records also the path taken by the mouse during the gaming session. This feature may be used, for example, to analyze path irregularities, such as the ones related to indecision or to attention deficit.

Example of the *Oral Hygiene* Theme

In this category there are two types of games, i.e., image selection and image sequencing. The 10 levels have different objectives, and their complexity is progressively increased as the level advances. The degree of difficulty was previously discussed and defined with the help of occupational therapists from

[1] https://www.djangoproject.com/start/overview/

[2] https://www.heroku.com/

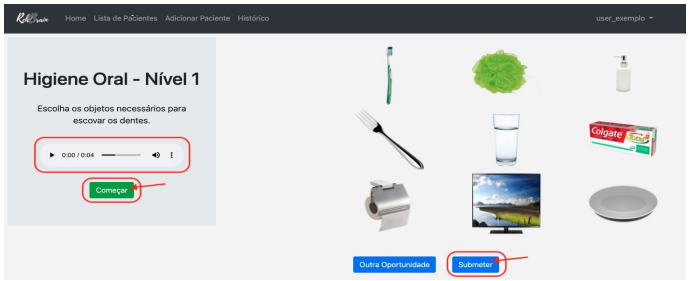

Figure 1: Example of a game from the oral hygiene theme, level 1. As written on the left portion of the screen, patients are asked to choose all objects required for brushing their teeth.

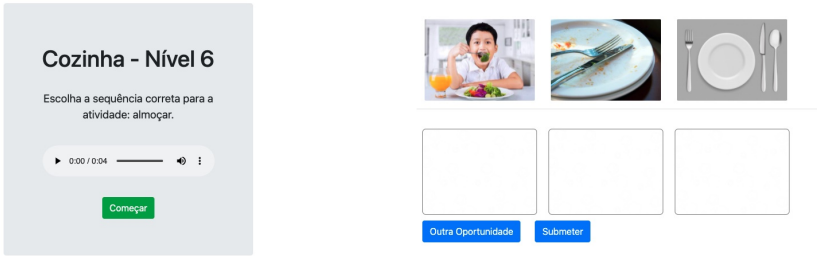

Figure 2: Example of a game from the kitchen theme, level 6. Patients are asked to choose the correct sequence of events for a meal, taking into consideration the proposed images.

the HCC, and it is up to the therapist to choose which game levels their patients should play in each rehabilitation session.

The first level of Oral Hygiene, illustrated in Fig. 1, is about selecting objects needed for the activity of brushing one's teeth. All levels have instructions on how to play expressed in writing and through a voice file, presented on the left-most part of the screen. The game is initiated by pressing the button "*Começar*", which means "Start". At the end of the task, the patient may choose between to submit ("*Submeter*") or to restart ("*Outra Oportunidade*").

Example of the *Kitchen* Theme

The kitchen levels, following the ones proposed for the Oral Hygiene and the Bath levels, are about selecting the correct objects, in this case related to food. In addition to the previous examples, we also added sequencing and categorization games to this theme. One example of level 6 is illustrated in Fig. 3, where patients are asked to sort the three pictures on top as a meaningful temporal sequence. Taking into consideration that motor skills may also have been impaired by the stroke, patients are not required to drag each picture to the correct place, but simply click the desired picture, which will be placed in the first available place in the sequence bellow.

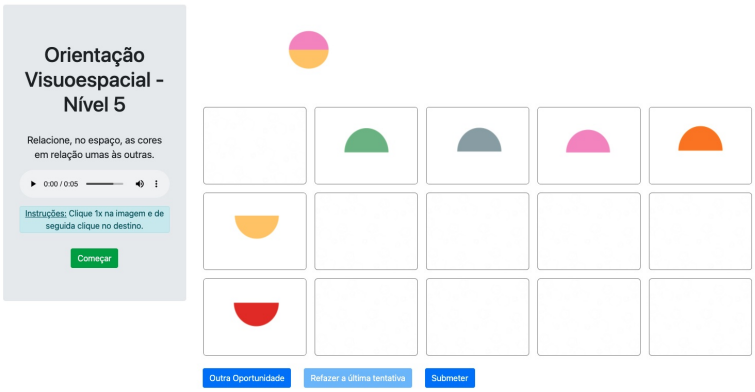

Figure 3: Example of a game from the Visuospatial Organization theme, level 5. Patients are asked to relate, spatially, the colours of the object above with the templates. The instructions on the left pane also include how to position the object on the grid – click on the object, to select it, and another time on the grid to place it.

Example of the *Visual Organization* Theme

With 12 levels of increasing complexity, games in this theme require the organization of objects on a grid, according to their shape, color, or orientation, within the space and in relation to other objects. There are three grid dimensions, varying with the level of the game. Levels 1–3 use 1×4 grids, in addition to one fixed column, on the left, and one line, on top. Levels 4–6 show 2×4 grids and levels 7–12 have 3×4 grids. The goal is to identify the cell in the grid that best matches the presented image. As with the previous example, patients click once on the proposed picture, and a second time in the cell where they want to move it to.

Figure 3 illustrates this theme, for an intermediate level of complexity. The patient needs to identify which top and bottom semi-circles form the proposed object. Since the grid dimension is rather large, a "Redo the last attempt" ("*Refazer a última tentativa*") option was added, to avoid the need to redo the complete game, in case of an unintended move. "Another chance" is still present, to restart that complete game.

Example of Mouse Path Recording

This is a feature of the platform that clearly differentiates RehbBrain from other perceptual or cognitive rehabilitation platforms. It gives healthcare professionals the possibility to review the mouse path, while playing any given game, confirming the patient's choices, searching and hesitations. The patient's mouse path appears as a black dotted line, overlayed to the screen of the played game, as illustrated in Fig. 4. This visualization is activated by pressing the button "Show mouse movement" ("*Mostrar movimento do rato*"). Although presented to the therapist after the patient played the game, the dotted line will appear at the same speed patients made their actual movements.

USABILITY TESTING

Two groups of users were recruited to test the usability of the proposed platform. The first comprised 5 occupational therapists, from Hospital Curry

Figure 4: Example of the mouse tracking functionality, overlayed to the hygiene game shown in Fig. 1.

Table 1. Results of the SUS questionnaire of the occupational therapist users.

Statements / Participants	1	2	3	4	5	6	7	8	9	10	Score
29	5	2	5	2	4	3	4	1	4	2	80
32	4	2	4	1	3	3	5	1	4	1	80
45	3	2	4	2	4	2	4	2	3	4	65
47	5	1	4	2	5	1	5	1	4	3	87,5
48	4	3	4	2	4	2	4	3	4	1	72,5
Average score											77,0
Confidence interval (95%)											6,70

Cabral, with high expertise in stroke rehabilitation programs. The other group comprised 44 individuals without associated pathologies or cognitive disorders.

They were asked to register on the platform and test all its functionalities, including the therapeutic games. They were then asked to complete a SUS questionnaire (SUS, September 2021). That questionnaire assessed the users' level of satisfaction when using the platform, as well as if there were errors and inconsistencies that needed improvement. Also important was to understand if the therapeutic games were clearly presented and easy to understand.

A SUS questionnaire consists of a 10-item questionnaire. Each item presents response options ranging from 1 to 5, where 1 corresponds to "Strongly Disagree" and 5 to "Strongly Agree" (SUS, September 2021). The final score ranges from 0 to 100. If that final score is lower than 51, it values the platform as "Terrible"; if it fits in the interval [51, 68[, it corresponds to "Poor"; whereas [68, 80.3[is "Good"; and if it exceeds 80.3, the evaluation is classified as "Excellent".

Table 1 displays the summarizing results of the SUS questionnaire for the specialist group of occupational therapists. Of the 5, 3 rated the platform as "Good", 1 as "Excellent" and 1 as "Poor". A justification for this low rating could be the score assigned to statement 10, by participant 45, which we consider to be due to a response error. The average rating obtained by the therapists was therefore "Good", with rather high degree of confidence.

After obtaining the usability feedback from the therapists, who were the first ones to evaluate the platform, their suggestions for improvement were implemented, prior to non-specialist testing. From the original 44 subjects considered only 33 returned their SUS questionnaire. A table with all 33 evaluations would be too lengthy for the manuscript's page limitations. Hence, only an overall analysis will be made herein. From the 33 participants in this group, 4 rated the platform as "Good" and the rest as "Excellent", with an average score of 90.2, and a confidence interval of 2.32.

Considering the responses given by both the occupational therapists and the group of non-health professionals, the average score obtained on SUS was 88.4, which classifies the platform as "Excellent".

To obtain more detailed feedback on the current functionalities of the platform, in addition to the SUS usability questionnaire, participants were asked 17 additional questions, which focused both on their experience of using the platform and the proposed games. Those were important to understand what needed to be improved. Although not built with the purpose of truly evaluating the platform, a similar 5 scale employed in the SUS questionnaire was used.

The results of the supplementary questions confirmed that the participants had a good experience when using RehbBrain. They found the platform functional, intuitive, and easy to use. The therapeutic games also received positive feedback, the way of playing proved to be simple and the tasks were clear and easily understandable.

CONCLUSION

The goal the current work was to improve RehbBrain, a software platform for perceptual and cognitive rehabilitation programs, which includes therapeutic games, designed to be used with stroke patients or suffering from other diseases that affect those mental skills. In addition to helping care takers record patients' progress and evaluate their evolution throughout therapy sessions, RehabBrain's serious gaming allow for dynamic, standardized and systematic therapeutic interventions, with a very clear focus on the personalization of said therapy, which complements more conventional strategies, such as traditional board and pencil and paper games.

In addition to helping to manage patients' therapy interventions, the platform currently has 42 therapeutic games, rooted on daily living tasks. As outcomes of playing them, the platform registers several parameters. The path covered by mouse, during the game, is one of the most useful and differentiating such parameters. It may be of great interest for clinical and research purposes alike, allowing for a deeper evaluation of the intervention programmes.

The functionality of RehbBrain was tested with a group of individuals without associated pathologies. The SUS questionnaire results obtained an overall average score of 88.4. Additional questions in usability tests confirmed that participants felt comfortable using the platform, that it is functional and easy to understand for patients and rehabilitation specialists. The simplicity and clarity of the proposed games received positive comments. In this

respect, occupational therapists from HCC manifested their intention to take the proposed technology into use within future regular therapy sessions.

Considering those observations, we conclude that RehbBrain complies with the objectives initially proposed, although there is margin for improvement. In particular, the functionality that allows for the analysis of mouse movements, while playing the proposed game, may be complemented in the future with tools that allow automatic and objective analyses of the path, through indicators based on the time the cursor remains in a certain point, speed, backtracking points, etc. As for the therapeutic games, the main suggestions are to explore different cognitive areas, such as memory, and to include games of greater cognitive demand.

Even taking into consideration the aforementioned evolutions of proposed platform, it is already fit for practical use, in order to help occupational therapists improve their rehabilitation routines, when dealing with stroke patients. Early use of RehbBrain was received with very positive feedback from therapists and patients alike.

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