Personalizing paper-and-pencil training for cognitive rehabilitation: a feasibility study with a web-based Task Generator

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Personalizing paper-and-pencil training for cognitive rehabilitation:

a feasibility study with a web-based Task Generator

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Abstract**—***Cognitive impairments impose important limitations in the performance of activities of daily living. Although there is important evidence on cognitive rehabilitation benefits, its implementation is limited due to the demands in terms of time and human resources. Moreover, many cognitive rehabilitation interventions lack a solid theoretical framework in the selection of paper-and-pencil tasks by the clinicians. In this endeavor, it would be useful to have a tool that could generate standardized paper-and-pencil tasks, customized according to patients' needs. Combining the advantages of information and communication technologies (ICT's) with a participatory design approach involving 20 health professionals, a novel web-tool for the generation of cognitive rehabilitation training was developed: the Task Generator (TG). The TG is a web-based tool that systematically addresses multiple cognitive domains, and easily generates highly personalized paper-and-pencil training tasks. A clinical evaluation of the TG with twenty stroke patients showed that, by enabling the adaptation of task parameters and difficulty levels according to patient cognitive assessment, this tool provides a comprehensive cognitive training.*

Keywords—Cognitive Rehabilitation; Personalization; Stroke; Technology Barriers.

I. Introduction

Cognitive impairments following stroke are common and are present in approximately 70% of patients in the acute stages of recovery [1], causing problems in activities of daily life and social participation. These cognitive impairments commonly include focal disorders, such as aphasia and neglect, as well as more diffuse abnormalities, such as slowed information processing and executive dysfunction [2]. Cognitive rehabilitation is the treatment of choice for these deficits and can be defined as a therapy designed to restore, substitute or compensate for lost cognitive abilities due to injury or illness. Additionally, it targets the improvement of skills by reestablishing or strengthening abilities that were intact prior to the loss [3].

Cognitive training has been proven to be successful in improving cognitive deficits after stroke [4] [5], but its efficacy highly depends on the intensity of treatment over an extended period of time. However, the implementation of cognitive training programs with the appropriate intensity and duration becomes difficult because of important limitations. First, the traditional intervention model requires multidisciplinary teams to manage exercises based on patients' profile and performance [6]. The cost of this process limits the intensity and length of the treatments, compromising its sustainability, accessibility and scalability, resulting in a large economic burden to both health systems and families [7]. Besides, the patient needs to travel to the rehabilitation center, making the duration of the treatment conditional to the patient's availability. Second, since patients usually need to travel to clinical facilities to receive rehabilitation, interventions are subject to the availability of vacancies and transportation [8]. Third and last, in the neuropsychological rehabilitation field there is an absence of clinical practice guidelines to allow a rational extension of these services. For instance, classic cognitive training mainly involve solving paper-and-pencil tasks under specialized supervision because they are clinically validated and have a reduced cost [9]. Unfortunately, these tasks selection and adjustment to the patient's needs generally lack a solid theoretical framework [10].

The American Congress of Rehabilitation Medicine (ACRM) conducted systematic reviews on a total of 370 studies about cognitive rehabilitation for people with TBI or stroke, published from 1971 through 2008 [11],[4],[5]. Cognitive rehabilitation was shown to be of greater benefit than conventional rehabilitation in 94.1% of the comparisons studies. According to this evidence, there is a clear indication that cognitive rehabilitation is the best available form of treatment for people who exhibit cognitive impairments and functional limitations after TBI or stroke [5]. However, Paiva and colleagues performed a meta-analysis on cognitive rehabilitation in stroke and the results suggested a lack of sufficient evidence to support or refute the efficacy of cognitive interventions in stroke patients [12]. These divergent results should be interpreted with caution since in this meta-analysis 504 of 507 studies were excluded due to its low quality, only 3 were considered by the authors. Additional research, using standardized assessment instruments and well-structured training programs, is needed to elucidate the mechanisms of change underlying the efficacy of cognitive rehabilitation.

An international group of researchers and clinicians (known as INCOG) recommends that cognitive assessment and rehabilitation should be tailored to the patient neuropsychological profile, premorbid cognitive characteristics and goals for life activities and participation [13]. The existing cognitive rehabilitation theories and models have been relatively successful when applied to focal cortical deficits (e.g. neglect and aphasia), but almost inexistent for more generalized cognitive impairment (e.g. slowed information processing and executive dysfunction) [14]. It is more challenging when we are addressing multiple aspects of cognition simultaneously. Hence, it is difficult to provide clear guidelines on how to parameterize cognitive training tasks and how to adapt them to the specific needs of each patient [15]. Currently, cognitive rehabilitation is mostly planned and delivered based on a selection of a limited set of paper-and-pencil cognitive tasks. Consequently, most cognitive training tasks may not be properly adjusted to the specific needs of each patient [9]. Further, task selection is also heavily grounded on the experience of the clinician - a type of knowledge that is difficult to objectively capture - therefore making it difficult to transmit and share [15].

Information and Communication Technologies (ICT's) based solutions such as serious games, Virtual Reality (VR) simulations or other computer mediated approaches, have an enormous potential for enhancing the intensity and personalization of cognitive rehabilitation by supporting the ability to carry out controlled, highly adaptive and ecologically valid tasks [16]. Over the past few years, several computer based solutions have been proposed to increase the availability and quality of cognitive training, flooding the marketplace with commercial brain exercise programs that claim to improve cognition and have diagnostic abilities [17] such as the CogWeb [18] and the Guttmann Neuro Personal Trainer [19], for instance.

VR offers the possibility to simulate daily tasks in a virtual environment, adapting the task parameters according to the patient performance, which increases training specificity and patient's motivation by avoiding boredom and frustration in a more sophisticated and ecologically valid approach [20]. Nevertheless, the clear enthusiasm for the use of technology in rehabilitation must be tempered by an acknowledgement of potential barriers, such its inherent costs, accessibility and usability by patients and healthcare professionals. Most virtual environments used in clinical studies are not commercially available and only a few research laboratories have access to them. Despite the proliferation of ICT's in cognitive rehabilitation, only 5-15% of people with disabilities have access to technological devices that can assist in the rehabilitation process [21]. Additionally, many healthcare providers are unfamiliar with VR technology, only about 27% of these professionals refer to use these computer assisted technologies in their rehabilitation interventions [22]. Also, technological interventions are subject to continuous maintenance and technical support, eventually resulting in delayed interventions or the need to reschedule. Such complications speak to the challenges of implementing interventions dependent upon technology within inpatient and outpatient rehabilitation settings. Any delays in these fast paced settings, requiring the coordination of various professionals, can be disruptive [23].

In order to increase the benefits of ICT's and to address its limitations, a web-based tool - the Task Generator (TG) – was developed through a participatory design approach with 20 rehabilitation professionals [24]. Besides integrating existing theories and models [10], it capitalizes on the solid aspects of existing computerized training protocols for cognitive rehabilitation [8], [18], [25]. The TG addresses multiple domains of cognitive functioning in a systematic and quantitative manner, generating a profile of cognitive demands for each task and enabling the clinician to easily deliver a highly adapted training program to each patient's deficits. Given that the TG ultimately generates paper-and-pencil training tasks, its application is compatible with the current practice and existing limitations of clinical settings.

This paper presents the main characteristics of the developed system and the results of a feasibility study with stroke patients. To evaluate the personalization of the TG tasks, we designed a study with the objective of answering two main questions: 1) Does TG personalization properly adapt to patient's needs? and 2) How accurate is the generated profile of cognitive demands of each task?

II. MATERIALS AND METHODS

A. Task Generator

The TG is a free and worldwide accessible tool (neurorehabilitation.m-iti.org/TaskGenerator), able to generate personalized paper-and-pencil cognitive rehabilitation programs in PDF format, composed by a set of 11 tasks (Table 1) gathered from clinical settings and parameterized through rehabilitation experts input.

TABLE I. LIST OF TRAINING TASKS AND THEIR OBJECTIVES.

Tasks	***Objectives***
Cancellation	Find a target stimulus in a pool of distractors.
Numeric Sequences	A numeric sequence is given and the subject has to come up with the missing numbers.
Problem Resolution	Two types of problems are presented, numeric calculations or calculations based on textual descriptions of daily activities.
Association	A number of randomized pairs of items need to be paired correctly.
Comprehension of Contexts	Some images are given with a number of descriptions. Correct descriptions need to be identified.
Image Pairs	A number of pairs of images to be memorized is presented and have to be recalled after 30 minutes.
Word Search	A number of words can be found up, down, forward, or diagonally in a pool of randomized letters.
Mazes	Finding the way out of a labyrinth.
Categorization	Grouping items into their underlying categories. The categories have to be guessed from the items.
Action Sequencing	A list of randomized steps needed for the execution of several activities of daily living is presented.
Memory of Stories	Recalling information about a read story or a picture by answering questions about it.

In short, 11 standard tasks have been operationalized according to how their different parameters impact different cognitive domains (Attention, Memory, Executive Functions, Language). This was achieved by means of a participatory design methodology involving 20 rehabilitation experts who rated multiple variations of the task parameters in terms of its cognitive demands [24].

1) *Individual Task Parameterization*

The TG is able to procedurally generate each of the 11 tasks individually by directly specifying the values of their parameters (Fig. 1). Every time a task is generated by the TG is different, even if sharing the exact same parameters. This allows for the repeated use of the tool, thus avoiding repetitiveness while making sure that the intrinsic parameters of each task are adjusted to the clinicians' specifications.

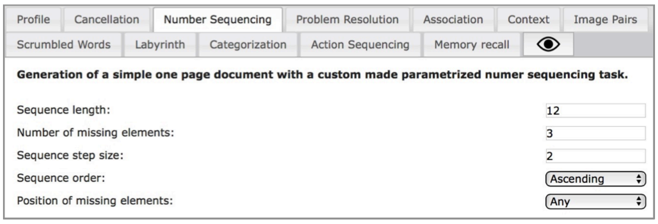

Fig. 1. Parameterization example of the Number Sequencing task, where task parameters can be manually selected.

2) *Task Profile*

All the generated tasks have a graphical representation of the profile of their cognitive demands (Memory, Attention, Executive Functions and Language) and overall Difficulty, enabling clinicians to intuitively visualize and interpret the generated training, being thus able to adapt it to each patient's needs (Fig. 2).

3) *Full Cognitive Training Program Generation*

Once a patient is assessed and the patient's deficits and general cognitive profile is known, the challenge of the clinician is how to select the best set of parameters for each specific patient. TG solves that problem by allowing clinicians to easily generate a complete cognitive training program containing the whole set of the 11 tasks by simply specifying the cognitive profile for a patient in 4 cognitive domains (Memory, Attention, Executive Functions, Language) and the overall task difficulty in a 1 to 10 scale (Fig. 3). This can be easily done through the characterization of the patient with validated instruments such as the MoCA [26]. After the characterization of a profile, a full training program is generated by pressing the "Generate Training" button and then downloaded as a pdf file by pressing the "Download PDF" button.

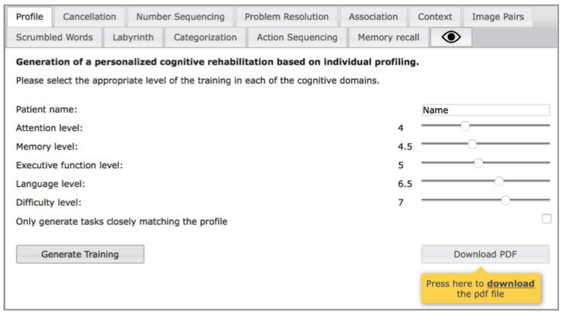

Fig. 3: Cognitive training program generation based on a specific patient profile.

4) *Training adaptation over time*

When the patient finishes a set of 11 tasks, the clinician may use one of these 2 procedures:

1) ***From training session to training session*** - By scoring the task performance using a 0 – 100% scale, and computing the mean performance of the 11 tasks set. If the mean performance is greater than a specific threshold (for instance assuming an optimal performance above the 70% [27]), the clinician should increase in 0.5 the difficulty parameter, while keeping the ones related to Memory, Attention, Executive Functions and Language constant.

2) ***After a progress evaluation point*** - Performing a new assessment of the patient profile and generating in a systematic and objective manner a new set of training tasks following the same procedure stated in the *Cognitive Training Program Generation* section.

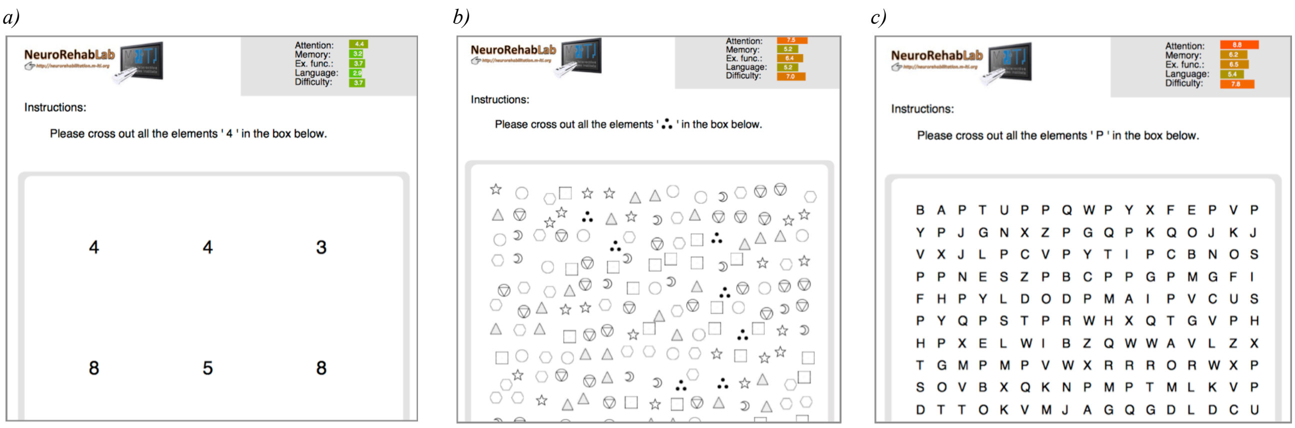

Fig. 2: Example of the Cancellation task with different parameter selection. The graphical profile changes according to the parameters defined by the clinician: a) Attention 2.5, Memory 3, Executive Functions 2.5, Language 3 and Difficulty 3.5; b) Attention 4.5, Memory 6, Executive Functions 7, Language 8 and Difficulty 7.5; c) Attention 9, Memory 6.5, Executive Functions 8.5, Language 5 and Difficulty 8.

B. *Clinical evaluation*

1) Participants

Participants were recruited at the Nélio Mendonça, João Almada and Santo António Rehabilitation Units (Madeira Health Service, Portugal), based on the following inclusion criteria: no vision deficits; capacity to be seated; non-aphasic and with sufficient cognitive ability to understand the task instructions (as subjectively assessed by the clinicians). The sample consisted of twenty (10 female, 10 male) middle-aged (*M*= 61.75 years old, *SD*=8.89) stroke patients (9 right hemisphere and 11 left hemisphere lesion), with a mean of 4.05 ± 3.73 months post-stroke, and with a mean schooling of 4.95 ± 4.03 years. The Madeira Health Service Ethical Committee approved the study and all the participants gave previous informed consent.

2) Characterization of patients' cognitive profile and training personalization

The cognitive profile of each participant was assessed with the Montreal Cognitive Assessment (MoCA) [26], a cognitive screening instrument that, besides a high sensitivity to post-stroke deficits [28], includes a reduced version of the Trail Making Test - version B [29], a representative measure of the executive functions domain. The TG *Attention* parameter was defined from MoCA's attention component score (0-6). The delayed recall and orientation scores (0-11) were used to parameterize *Memory*. *Executive Functions* were parameterized through the sum of the visuospatial, executive and abstraction MoCA sub-scores (0-7). Finally, MoCA's naming and the language scores (0-6) were used to parameterize *Language*. The MoCA total score (0-30) was used to parameterize the overall *Difficulty* of the TG training. All TG parameters were normalized on a scale 1-10 and a personalized training was generated for each participant, and printed on paper. Participants completed the generated tasks in two sessions of 30 to 45 minutes with the assistance of a psychologist.

3) Data analysis

The Statistical Package for the Social Sciences v.20 was used for the data analysis. Missing data were replaced through the single regression method. The normality of the distribution was assessed using the Kolmogrov-Smirnov test and, because most distributions deviated from normality, non-parametric correlations (Spearman *rho*) were performed.

In order to analyze task performance in each cognitive domain, we applied the following formula:

$$Domain\ _iPerformance = \sum_{j=0}^{10} \frac{(Task_j\_performance * Task_j\_Domain_i\_demands)/10}{11}$$

where $Domain_i$ *Performance* is a metric that measures in percentage the contribution of each cognitive domain (Memory, Attention, Executive Functions, Language) taking into account the cognitive demands of each generated $Task_j$. This approach allows us to correct task performance for the amount of challenge posed. That is, 100% task performance on a task that has 5 points (out of 10) Memory demands results on a 50% Memory performance, and so on and so forth.

III. RESULTS

According to the Kolmogorov-Smirnov (KS) test, data were normally distributed for age (KS=.147, p=.200) but not for gender (KS=.335, p<.001), years of schooling (KS=.293, p<.001), stroke location (KS=.361, p<.001) and time post-stroke (KS=.261, p=.001). Data were normally distributed concerning the cognitive assessment with the MoCA (KS=.149, p=.200) and the performance in the TG (KS=.236, p=.005).

A. *Does the TG personalization adapt to the patients' needs?*

When comparing the patients' overall performance in MoCA and that in the adapted TG tasks, we observe that patients showed higher performances that those of their cognitive assessment (Z=-3.808, p<.001) (Fig. 4). This indicates that patients with lower MoCA scores were presented with easier tasks, thus scoring higher. Consistent with this finding, we found a moderate correlation (r_s=.520, p=.019) between performance in the TG training (Mdn=83.25, IQR=67.88-91.5) and cognitive functioning as assessed by MoCA (Mdn=18, IQR=16-21.75, strongly suggesting that TG task performance is not only determined by the skillset of the patient. Hence, these data are consistent with the notion of a successful adaptation of the TG training parameters based on the cognitive characterization of each patient, increasing the average task performance and dissociating it from the cognitive skillset of the patient.

In addition, our data shows that more difficult tasks were automatically assigned to the participants performing at a higher level. That is, regardless of the task adaptation procedures, a very strong correlation (r_s=.872, p<.001) was found between the average TG task performance (Mdn=83.25, IQR=67.88-91.5) and the difficulty setting assigned to those patients by the TG (Mdn=4.83, IQR=3.24-6.43). This finding suggests that the personalization of the challenge of each task was properly adapted to the capabilities of each patient.

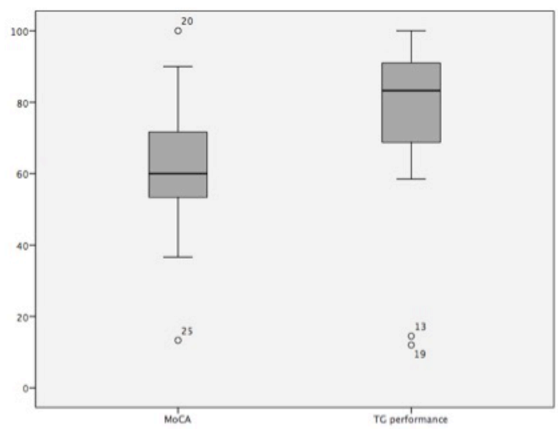

Fig. 4. Comparison of MoCA assessment vs. TG performance scores. MoCA scores were converted to a 0-100 scale to allow comparison.

B. *How accurate is the generated profile of cognitive demands of each task?*

To address this question, we considered the Domain Performance metric - task performance weighed by their demand in each cognitive domain – as described in the Data Analysis section. This allows us to consider both task performance and personalization in a single metric. That is, a 100% performance in a task of difficulty 5 is equivalent to a 50% performance on a task of difficulty 10.

A strong correlation (r_s=.686, p=.001) was found between the performance in attention (Mdn=5.25, IQR=3.55-6.19) and the MoCA attention score (Mdn=3, IQR=3-4.75). Between the performance in memory (Mdn=3.97, IQR=293-5.23) and the MoCA memory score (Mdn=8, IQR=6-8.75) the correlation was also strong (r_s=.730, p<.001). The performance in the executive functions (Mdn=4.91, IQR=3.74-5.8) was also strongly correlated (r_s=.742, p<.001) with the MoCA executive functions score (Mdn=4, IQR=2.25-4.75). Finally, the performance in language (Mdn=3.43, IQR=2.66-4.37) and MoCA language score (Mdn=4, IQR=2-5) was moderately correlated: r_s=.475, p=.034 (Table 2).

TABLE II. SPEARMAN CORRELATIONS BETWEEN THE TG PERFORMANCE (WEIGHED BY THEIR DEMAND IN EACH COGNITIVE DOMAIN AND TOTAL SCORE) AND THE MOCA SUBDOMAINS SCORES.

	MoCA Attention	**MoCA Memory**	**MoCA Executive**	**MoCA Language**
TG Attention	.686**	.662**	.621**	---
TG Memory	.755**	.730**	.773**	---
TG Executive	.723**	.721**	.742**	---
TG Language	.682**	.688**	.719**	.475*
TG Total	.492*	.507*	.460*	---

*** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.*

C. *Reliability of the training*

The internal consistency of the TG training was assessed through the Cronbach's alfa, using the median performance of each task. The TG revealed and acceptable internal consistency (α=.786) which means that, despite the great diversity in the type of training tasks, the consistency in its performance is acceptable. By performing this reliability analysis removing the Image Pairs task, a greater internal consistency level (α=.818, which is good) is obtained.

IV. DISCUSSION

In this paper we presented a feasibility study with the TG, a web-based tool that was developed through the combination of guidelines from a participatory design approach with 20 rehabilitation professionals, ICT's and existing rehabilitation models and theories. The TG enables the parameterization and generation of personalized cognitive paper-and-pencil training tasks. A clinical study with stroke patients has led us to four main conclusions concerning the feasibility of this web-based tool.

First, we can determine that, although moderately correlated, the TG training performance is higher and statistically different from the patients general cognitive functioning, as assessed by the MoCA. This finding leads us to conclude that performance is modulated by the TG adaptation. Second, our results demonstrate that more difficult tasks were assigned to the patients that could perform at higher levels. This finding indicates that our personalization adapts properly to each patient's skillset, providing an adaptive challenge level. Finally, we found moderate and strong correlations between attention, memory, executive functions and language assessment scores with the TG performance in the corresponding domains. These results largely support the existing task profiling, that is, the methodology used to quantify how each task impacts demands on each domain. Consequently, since our *Domain Performance* is correlated with the scores of all MoCA subdomains, this suggests that it may be possible to rely on actual TG task performance to provide an iterative TG training adaptation without requiring repeated clinical assessments.

Finally, the TG was very well received by patients and rehabilitation professionals, who showed interest and motivation to use it in the future.

V. CONCLUSIONS

We believe that the TG contributes towards the definition of objective procedures for the application of adaptive cognitive rehabilitation through the use of ICT's. The use of TG has virtually zero cost associated and can be widely deployed at healthcare centers. This new approach does not interfere with current clinical practices. By enabling the adaptation of task parameters and difficulty levels according to patient performance, this tool provides a comprehensive and highly personalized cognitive training. Given the encouraging results of this study, we are performing a longitudinal clinical trial to measure the impact of intensive cognitive training with the TG. In the meantime, the TG will continue to evolve with the development of more exercises.

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