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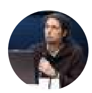

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ABSTRACT
Cognitive impairments impose important limitations in the performance of activities of daily living. Although there is important evidence on cognitive rehabilitation benefits, its implementation is limited due to time and human resources demands. 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, parameterized according to patients' needs. In this paper, we combine the advantages of information and communication technologies with a participatory design approach with 20 health professionals to develop a novel cognitive rehabilitation web-tool: the NeuroRehabLab Task Generator (NTG). The NTG is a free and online available tool that systematically addresses multiple cognitive domains, and easily generates highly personalized paper-and-pencil training tasks. A field evaluation of the NTG with ten stroke patients showed moderate and strong correlations of patients' task performance with their cognitive assessment in multiple cognitive domains. That is, corroborating its usefulness both as an assessment and as rehabilitation tool.

Categories and Subject Descriptors
J.3 [Computer Applications]: Life and Medical Sciences - health; K.4.2 [Computers and Society]: Social Issues – assistive technologies for persons with disabilities.

General Terms
Performance, Design, Human Factors, Standardization.

Keywords
Cognitive Rehabilitation, Personalization, Stroke.

1. INTRODUCTION
Cognitive impairment affects a person's capability to carry out activities of everyday living and are present in 3-19% of people older than 65 years [1]. Cognitive impairment is increasing globally because of the aging of the population. Projections indicate that by 2050 the number of individuals older than 60 years will be approximately 2 billion and will account for 22% of the world's population [1]. Every year 15 million people suffer from stroke, 10 million are affected by Traumatic Brain Injury, and 7.7 million are diagnosed with Dementia [2]. Hence, there is an urgent need to develop cognitive training tools to maximize neural plasticity and improve functional independence [3].

Despite the existence of irrefutable experimental evidence about the benefits of cognitive training in rehabilitation [4], the implementation of cognitive training programs with the appropriate intensity and duration fails because of important limitations. First, the traditional intervention model requires a psychologist to manage exercises based on patients' profile and performance [5], which is not always possible. Second, the demand on time and human resources limits the intensity and length of interventions, compromising their impact. Third and last, since patients usually need to move to clinical facilities to receive rehabilitation, interventions are subject to the availability of vacancies and transportation [6].

Although paper-and-pencil tasks are widely used in the cognitive rehabilitation field because of their clinical validity and reduced cost [7], their selection and adjustment to the patient's needs generally lack a solid theoretical framework [8]. Cognitive rehabilitation is mostly planned and delivered based on the experience of the clinician, and based on a selection of a limited set of available paper-and-pencil cognitive tasks. Unfortunately, these tasks are generally not properly adjusted to the specific needs of each patient [7]. The existing cognitive rehabilitation theories and models have been relatively successful when applied to focal cortical deficits (e.g. neglect and aphasia), but less for more generalized cognitive impairment (e.g. slowed information processing and executive dysfunction) [9]. Currently, there is no quantitative cognitive rehabilitation framework that addresses the multiple aspects of cognition and can provide us with clear guidelines on how to parameterize cognitive training tasks and how to adapt them to the specific needs of each patient [10].

Information and Communication Technologies (ICT) based solutions such as games, Virtual Reality (VR) 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 [11]. One of their main advantages is the possibility of adapting the task parameters and difficulty levels according to the patient performance, which increases training specificity and patient's motivation by avoiding boredom and

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frustration [12]. Although these tools can provide an accessible and intensive training, they still involve the use of technologies that are mostly unavailable in most clinical settings.

In order to maximize the benefits of ICT, it would be advantageous to have a tool that is compatible with the current practical limitations of clinical settings and that capitalizes on the solid aspects of existing cognitive rehabilitation instruments, yet being able to provide a comprehensive and highly personalized cognitive rehabilitation program. In this endeavor, besides integrating existing theories and models, we involved stakeholders in the development of a comprehensive framework for the design of a personalized cognitive rehabilitation program [13], through standard and widely accepted paper-and-pencil tasks, and adapted to the profile of each patient. Here we present the "NeuroRehabLab Task Generator", a web-based cognitive task generator, developed through a participatory design approach. Besides addressing multiple domains of cognitive functioning in a systematic and quantitative manner, this web-tool can easily deliver a highly adapted training program to each patient's deficits. Here we present its evaluation in a pilot study with 10 stroke patients.

2. Methods

2.1 NeuroRehabLab Task Generator

The "NeuroRehabLab Task Generator"[1] (NTG) is a free and worldwide accessible tool for clinicians, able to generate paper-and-pencil personalized cognitive rehabilitation programs in PDF format composed by a set of 11 standardized tasks gathered from clinical settings and parameterized through a participatory design approach. 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 67 permutations of task parameters of the following cognitive training tasks (Figure 1):

(1) *Word Search:* A number of words can be found up, down, forward, or diagonally in a pool of randomized letters. This task was operationalized according to the *number of words* to find and the *existence of clues* to identify words (pictures, words or none).

(2) *Problem Resolution:* Two *types of problems* are presented, numeric calculations or calculations based on textual descriptions of daily activities. Problems vary according to the *number of operations* involved and the use of numbers with *ones* or *tens*.

(3) *Numeric Sequences:* A numeric sequence is given and the subject has to come up with the missing numbers. The task can be operationalized according to the number of *missing numbers* (*one, two or three*), their *position* and the *step size* between numbers.

(4) *Action Sequencing:* A list of randomized steps needed for the execution of several activities of daily living is presented. The number of steps to be ordered can be defined, and whether the *goal* of the task is explicitly mentioned or has to be guessed.

(5) *Association:* The task comprehends a *number* of randomized pairs of items. These items need to be paired correctly, according to a logical relationship between them.

(6) *Cancellation:* The purpose is to find a target stimulus in a pool of distractors. This task is operationalized according to the *type of stimulus* (letters, symbols, numbers), the *pool size* and their *arrangement* (randomly organized or in a grid structure).

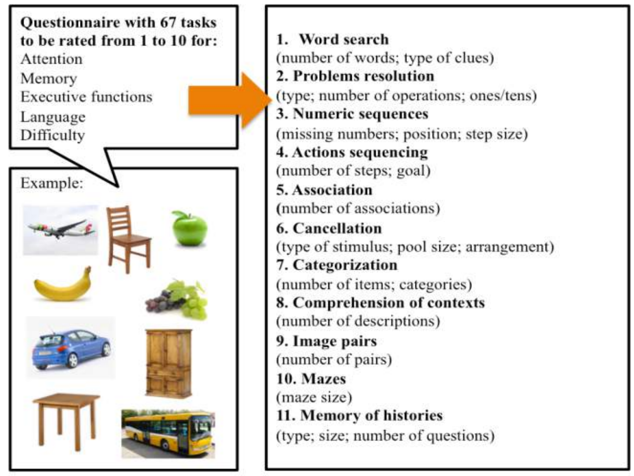

Figure 1: Computational modeling of the participatory design results enabled the adaptation of task parameters.

(7) *Categorization:* This task consists of grouping items into their underlying categories. The categories have to be guessed from the items. The task can be varied according to the *number of categories* and number of *items*.

(8) *Comprehension of Contexts:* In this task some images are given with a *number of descriptions*. *Correct descriptions* need to be identified.

(9) *Image Pairs:* In this task a *number of pairs* of images are presented to be memorized. They have to be recalled after 30 minutes.

(10) *Mazes:* The task consists of finding the way out of a labyrinth. Task can be operationalized according to the maze *size*.

(11) *Memory of stories:* The task consists of recalling information about a read story or a pictorial scenario by answering questions about it. Stories can be textual or pictorial (*type*), can have several descriptive elements (*size*), and a variable *number of questions*.

2.1.1 Task Parameterization

NTG is a web based application that comprehends the above 11 cognitive training tasks. NTG is able to procedurally generate each of the 11 tasks individually, by directly specifying the values of their parameters (Figure 2). Every task generated by the NTG is different, even if sharing the exact same parameters. This allows for the repeated use of the tool, thus avoiding learning effects while making sure that the intrinsic parameters of each task are adjusted to the clinician's specifications.

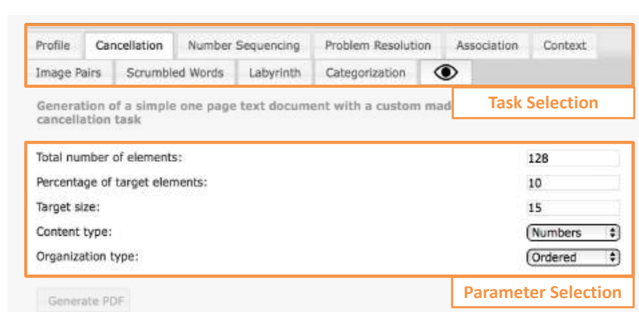

Figure 2: Cancellation task parameterization example.

[1] Accessible at http://neurorehabilitation.m-iti.org/TaskGenerator/

Figure 3: Example of different parameter selection of the Cancellation task. The graphical profile changes according to the parameters defined by the clinician.

2.1.2 *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 (Figure 3), enabling clinicians to intuitively adapt the training to each patient's needs.

2.1.3 *Cognitive Training Program Generation*

Once a patient is assessed and the deficits and general cognitive profile is known, NTG allows clinicians to easily generate a complete cognitive training program containing the whole set of the 11 tasks by simply defining the cognitive profile for a patient in 4 cognitive domains (Memory, Attention, Executive Functions, Language) and the overall task difficulty (Figure 4). After the definition of a profile, a full training program can be generated by pressing the "Generate Training" button and then downloaded as a pdf file by pressing the "Download PDF" button.

2.2 Evaluation

2.2.1 *Participants*

Participants were recruited at the Nélio Mendonça and João Almada Hospitals (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 assessed by the clinicians. The

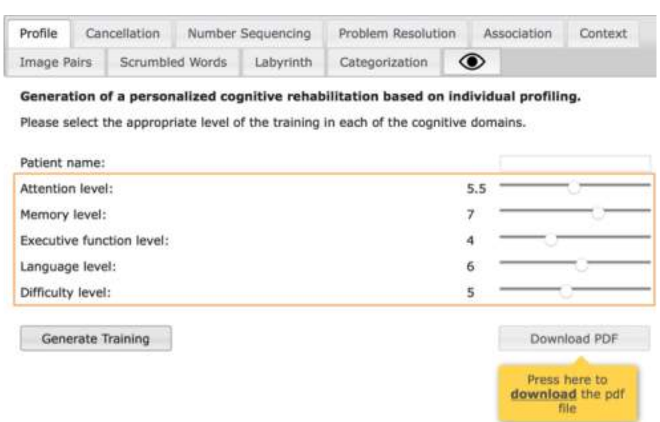

Figure 4: Cognitive training program generation based on the patient assessment.

sample consisted of ten (9 female, 1 male) middle-aged (*M*= 53.20 years old, *SD*=17.53) stroke patients (7 right hemisphere, 2 left hemisphere and 1 cerebellum), with a mean of 17.20 ± 30.28 months post-stroke, and with a mean schooling of 9 ± 6.07 years. The Madeira Health Service Ethical Committee approved the study and all the participants gave previous informed consent.

2.2.2 *Protocol*

The cognitive status of each participant was assessed with the Addenbrooke Cognitive Examination (ACE) [14], a commended cognitive screening instrument for this clinical population [15]. The ACE total score (0-100) was used to establish the profile for the cognitive training. For instance, if the ACE result was 74/100, the selected profile in the NTG would be 7.5/10 for all cognitive domains. A personalized training was generated for each participant and printed on paper. Each participant completed a subset of tasks considered feasible to be realized in a single training session of 30 to 45 minutes: Cancellation, Numeric Sequences, Image Pairs, Association, Mazes and Categorization.

2.2.3 *Data analysis*

The Statistical Package for the Social Sciences v.20 was used for the data analysis. 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.

3. Results

3.1 Is the performance of the training tasks representative of cognitive functioning?

We found a strong correlation (r_s=.832, p=.003) between the average performance in the NTG tasks in a 0-100 scale (Mdn=88.3, IQR=41) and the cognitive functioning, as assessed by ACE (Mdn=74, IQR=38), revealing that total performance is representative of cognitive functioning as assessed by the ACE (Figure 5).

3.2 How accurate is the generated profile of cognitive demands of each task?

When considering task performance weighed by their demand in each cognitive domain, a strong correlation (r_s=.778, p=.008) was found between the performance in executive functioning (Mdn=5.27, IQR=3.17) and the ACE executive functions score (Mdn=6; IQR=8); in memory (Mdn=4.50, IQR=2.29) a significant correlation (r_s=.693, p =.026) was found with the ACE memory score (Mdn=20, IQR=17); as well as performance in language

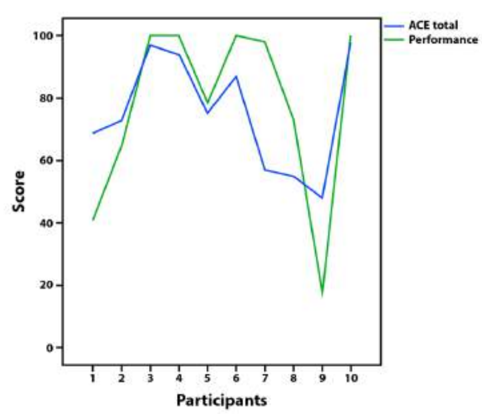

Figure 5: ACE total and Performance are strongly related.

(Mdn=3.9, p=1.48) and ACE language score (Mdn=23, IQR=6): r_s=.654, p=.040. We found no significant correlation between tasks performance in attention (Mdn=5.17, IQR=2.36) and ACE attention score (Mdn=17, IQR=5): r_s=.472, p=.168. These results largely support the existing task profiling, and suggests that it is possible to assess cognitive functioning, consistent with ACE, directly through the analysis of task performance.

3.3 Does NTG personalization adapt to patients needs?

A very high correlation (r_s=.944, p=.000) was found between the total task performance (Mdn=88.3, IQR=41) and the difficulty setting generated by NTG (Mdn=5.53, IQR=4.20), which indicates that more difficult tasks were assigned to the participants performing at a higher level. That is, the personalization of the challenge of each task was properly adapted to the capabilities of each patient.

4. Discussion

In this paper we presented the development of the NeuroRehabLab Task Generator, which is the result of a participatory design approach with 20 rehabilitation professionals. A computational modeling approach, together with the use of ICT's, resulted in a tool that enables the parameterization and generation of cognitive training tasks.

The clinical evaluation of the tool with stroke patients has led us to three main conclusions. First, we can determine that NTG training performance is representative of cognitive functioning since it is strongly correlated (r_s=.832, p=.003) with the ACE total score. Second, we found moderate and strong correlations between memory (r_s=.693, p =.026), language (r_s=.654, p=.040) and executive functions (r_s=.778, p=.008) assessment scores with the ACE performance in the corresponding domains. This correlation was not found for attention, which might be because the ACE incorporates also Orientation in the attention domain, which is not targeted by the attention NTG training. Third and last, our results demonstrate that patients who perform better are the ones with the higher difficulty parameters (r_s=.944, p=.000), which means that our personalization adapts properly to each patient's skillset.

5. Conclusion

We believe that the NTG contributes towards the definition of objective procedures for the application of adaptive cognitive rehabilitation through the use of ICT's. The use of NTG has virtually zero cost associated and can be widely deployed at healthcare centers. 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 intend, as a future step, to perform a randomized controlled trial involving a bigger number of patients.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] World Health Organization, "The World Health Report 2008: Primary health care (now more than ever)", 2014.

[2] World Health Organization, "Fact sheets," Available: www.who.int/mediacentre/factsheets/en/.[Accessed: 10-Jul-2015].

[3] B. A. Wilson, "Compensating for Cognitive Deficits Following Brain Injury," *Neuropsychol. Rev.*, vol. 10, no. 4, pp. 233–243, Dec. 2000.

[4] K. D. Cicerone, D. M. Langenbahn, C. Braden, J. F. Malec, K. Kalmar, M. Fraas, T. Felicetti, L. Laatsch, J. P. Harley, T. Bergquist, J. Azulay, J. Cantor, and T. Ashman, "Evidence-Based Cognitive Rehabilitation: Updated Review of the Literature From 2003 Through 2008," *Arch. Phys. Med. Rehabil.*, vol. 92, no. 4, pp. 519–530, Apr. 2011.

[5] B. A. Wilson, "Cognitive Rehabilitation: How it is and how it might be," *J. Int. Neuropsychol. Soc.*, vol. 3, no. 05, pp. 487–496, 1997.

[6] J. Solana, C. Cáceres, A. García-Molina, E. Opisso, T. Roig, J. M. Tormos, and E. J. Gomez, "Improving Brain Injury Cognitive Rehabilitation by Personalized Telerehabilitation Services: Guttmann Neuropersonal Trainer," *Biomed. Health Inform. IEEE J. Of*, vol. 19, no. 1, pp. 124–131, 2015.

[7] T. D. Parsons, "Ecological Validity in Virtual Reality-Based Neuropsychological Assessment," in *Encyclopedia of Information Science and Technology*, Hershey, PA: Information Science Reference, 2015, pp. 1006–1015.

[8] B. A. Wilson, "Towards a comprehensive model of cognitive rehabilitation," *Neuropsychol. Rehabil.*, vol. 12, no. 2, pp. 97–110, 2002.

[9] T. B. Cumming, R. S. Marshall, and R. M. Lazar, "Stroke, cognitive deficits, and rehabilitation: still an incomplete picture," *Int. J. Stroke*, vol. 8, no. 1, pp. 38–45, Jan. 2013.

[10] F. Gracey and B. A. Wilson, "Theoretical approaches to cognitive rehabilitation," in *Clinical Neuropsychology: A Practical Guide to Assessment and Management for Clinicians*, L. H. Goldstein and J. E. McNeil, Eds. John Wiley & Sons, Ltd, 2013, pp. 463–466.

[11] E. B. Larson, M. Feigon, P. Gagliardo, and A. Y. Dvorkin, "Virtual reality and cognitive rehabilitation: A review of current outcome research," *NeuroRehabilitation*, vol. 34, no. 4, pp. 759–772, Jan. 2014.

[12] K. E. Laver, S. George, S. Thomas, J. E. Deutsch, and M. Crotty, "Virtual reality for stroke rehabilitation," in *Cochrane Database of Systematic Reviews*, John Wiley & Sons, Ltd, 2015.

[13] P. L. Weiss, S. V. G. Cobb, and M. Zancanaro, "Challenges in developing new technologies for special needs education: a force-field analysis," in *10th International Conference on Disability, Virtual Reality and Associated Technologies*, Gothenburg, Sweden, 2014.

[14] E. Mioshi, K. Dawson, J. Mitchell, R. Arnold, and J. R. Hodges, "The Addenbrooke's Cognitive Examination Revised (ACE-R): a brief cognitive test battery for dementia screening," *Int. J. Geriatr. Psychiatry*, vol. 21, no. 11, pp. 1078–1085, 2006.

[15] K. Morris, V. Hacker, and N. B. Lincoln, "The validity of the Addenbrooke's Cognitive Examination-Revised (ACE-R) in acute stroke," *Disabil. Rehabil.*, vol. 34, no. 3, pp. 189–195, Feb. 2012.