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Evaluation of an ontology-based system for computerized cognitive rehabilitation

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ABSTRACT

Objectives: This paper describes the results of a randomized clinical trial about the effectiveness of a computerized rehabilitation treatment on a sample of 31 patients affected by Parkinson disease.
Methods: Computerized exercises were administered by the therapists to the intervention group (n = 17) through the CoRe tool, which automatically generates a big variety of exercises leveraging on a stimuli set (words, sounds and images) organized into a dedicated ontology. A battery of standard neuropsychological tests was performed for patients' assessment at baseline, after the treatment (that lasted 1 month), and after 6 months from the treatment stop. The control group underwent a sham intervention.
Results: Results show a statistically significant clinical benefit from computerized rehabilitation with respect to sham treatment. For the intervention group, response time and response accuracy were integrated into a weighted score that accounts also for the specific cognitive burden of each exercise. Differently from the control group, the majority of patients in the intervention group showed an improvement in that score, more marked in the first week of treatment, and which lasts for the entire treatment period, which could account both for a quick learning effect and for an improvement of cognitive conditions. Good usability of CoRe, already observed in previous studies, was confirmed by the present trial, where the percentage of protocol completion in the intervention group is very high (all but one patient are above 90%).
Conclusions: The CoRe system showed to be effective to improve some cognitive abilities in patients with Parkinson disease. However, after the end of the training, the benefit is hardly maintained over time. These findings support the implementation of CoRe in the clinical routine and the continuation of the treatment after discharge through the use of a homecare version of the system.

1. Introduction

The loss of cognitive functions can be directly associated to lesions of dedicated brain structures, the causes of which could be degenerative pathologies like multiple sclerosis, Parkinson's disease, Alzheimer's disease (of mild/moderate entity), brain injuries, strokes and other cerebrovascular diseases, outcomes of encephalitis and surgical procedures (e.g., brain tumor surgery). The damage can result in a reduction or, in particularly serious cases, a total loss of specific abilities. These pathologies cause several impairments, among which neglects (inability to perceive a part of the space), agnosia (difficult recognition of objects and/or people), memory loss, dyscalculia, aphasia, attention deficit, and impairments in logical-executive functions. Emotional and psychological problems like irritability, depression and anxiety can also arise, that worsen the overall condition and lead to reduction of motivation. This can compromise the patient's compliance to the proposed treatment.

The goal of cognitive rehabilitation, pursued through stimulation and exercise of compromised functional areas, is a slowing down of the cognitive decay or, when possible, the restoration of those functions [1]. The amelioration in the cognitive condition is associated to an improvement of the personal well-being (quality of life) and a subsequent facilitation of the readjustment to familiar and social environment.

This process is made possible by the so-called neural plasticity, that is the nervous system's capability of structural and functional modifications in response to particular, not exclusively pathological, events. Recent literature highlights how neural plasticity can be observed in lesions occurred both during the developmental stage and in adulthood. Studies also suggest that post-lesional training can help plasticity and restoration of cognitive functions [2]. An interesting review [3] is especially focused on cognitive treatment of elderly people.

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Cognitive rehabilitation is a primary topic of interest in neurorehabilitation research for several years. The first literature date back to the 1960s, but for a long time the target population of these studies was almost entirely composed by pediatric patients showing behavioral and speech impairments. That is why, in the 1970s, videogames were among the first technologies applied to cognitive rehabilitation [4]. In time, treatments have been extended to many categories of adult patients afflicted by the already mentioned degenerative diseases [5]. In parallel, the commercial availability of personal computers and the introduction of technology in medical treatment opened the way to computerized cognitive rehabilitation for patients of all ages.

Unfortunately, as discussed in the next section, still there are few evaluation studies showing the true applicability and effectiveness of those systems, which also for this reason are not entered the clinical routine of most centers yet. Aim of this work is to bridge this gap for the CoRe (Computerised Rehabilitation) system that we developed during last years. In previous papers [6–8] we described the system, which is a software tool that automatically generates patient-tailored exercises using a big set of stimuli (about 6000) organized into an ontology. In this paper we present the results of the first clinical evaluation study of CoRe, performed through a rigorous, randomized, controlled clinical trial on a set of patients affected by Parkinson disease.

2. Background

The evaluation of the efficacy of cognitive rehabilitation is a challenging task. Despite numerous studies in the literature, results are not yet conclusive. A recent Cochrane review states the following: “We identified insufficient high-quality evidence to reach any generalised conclusions about the effect of cognitive rehabilitation on executive function, or other secondary outcome measures …” [9]. The wide etiological variety characterizing these patients’ condition, as well as the numerous therapeutic approaches, often hamper gathering a population sample numerous and homogeneous enough to produce statistically significant results within a clinical study. Besides, due to this extreme variability, it is very complex to define a standard training protocol suitable for the whole patient sample. In some cases, this could even become counterproductive for the specific patient’s recovery. All these difficulties turn cognitive rehabilitation into a very interesting challenge in the field of personalized medicine.

A further issue concerns data collection: the most common approach to rehabilitation implies the administration of “pen and paper” exercises, as well as the manipulation of physical objects. Patients must solve tasks given by therapists during encounters lasting 30–90 min, depending on the type and entity of their impairments. Management and analysis of performance data are thus particularly complex and require the therapists to manually annotate patients' answers and response times. It's not uncommon for this activity- usually performed at the end of the visit or even the work day- to be affected by imprecisions and omissions. Besides, therapists have to autonomously organize data in order to be able to follow and evaluate the temporal evolution of each patient's performances.

The stimuli choice also represents a problem: picking texts, images and sounds to be used during exercises is a pivotal matter in the execution of the therapy. There are commercially available items to help the therapists, e.g. the cardboard cards by “La Favelliana”[1] (depicting daily life situations and, in general, visual elements) that can be administered to the patients during descriptive exercises or memory-based tasks. It is clear that the number of possible stimuli is limited, and the probability of showing the same ones to a patient in a short time span is very high. This very likely could lead not only to a learning effect which could damage the rehabilitation, but also to boredom, frustration and reduction of the patient's compliance towards the therapy.

[1] www.logopedia.com, last (Access 8th May 2017).

Those limits of the “analog” therapy are the main reason why several research groups proposed a computerized approach to cognitive rehabilitation starting from the 1980s, when the first PCs became commercially available.

Even when cognitive rehabilitation is computerized, obtaining proofs of its effectiveness is not easy, though data collection and performance measurement are undoubtedly made easier and more reliable. A systematic review [10] of 151 studies published between 1984 and 2011 regarding the effectiveness of computerized intervention for conservation and improvement of cognitive functions in healthy elderly concluded that *“Overall, findings are comparable or better than those from reviews of more traditional, paper-and-pencil cognitive training approaches suggesting that computerized training is an effective, less labor intensive alternative."*. Besides, *“Most studies reported older adults did not need to be technologically savvy in order to successfully complete or benefit from training."*

A recent meta-analysis [11] shows a significant improvement of general cognitive performances, but results vary according to the specific function examined: while the improvement in memory and elaboration speed is substantial, the same does not happen to attention and executive functions. Finally, home treatments carried out without therapists' supervision and a high frequency of treatment reveal inefficient. Lack of motivation, fatigue and other causes of non-compliance could be the reason of these results.

Studies on the use of virtual reality also show variable and non-conclusive results [12–18].

This uncertainty motivates the implementation of further studies like the one reported in this paper.

3. The CoRE system

Ontologies have been recognized as suitable knowledge representations in medical informatics applications [19,20]. CoRe is based on an ontology of stimuli as well (words, images and sounds, better illustrated in the supplementary material).

CoRe features seven main components (see Fig. 1):

1 The above mentioned stimuli ontology, characterized by almost 6000 concepts organized in taxonomies, described by attributes and connected to one another through relationships;
2 a database *(Patient_db)* to store performance data monitored during rehabilitation therapy, as well as personal information (*patient profile*) like hobbies, family member names, preferences (sports, colors, animals, etc) that are fundamental for the exercise personalization;
3 a database (*Stimuli_db*), created starting from the ontology, to store the available stimuli and make them work properly with other system components; it also contains all the parameters needed for the automatic modulation of difficulty;
4 the front-end: a graphical interface that allows the therapist to set the parameters required for the execution and the dynamic generation of the exercises;
5 the back end: a software engine for the dynamic generation of the exercises based on their formal description and the parameters selected by the therapist;
6 a set of personalized peripherals (alternative keyboards, switches, etc.) that allow patients to perform the exercises using means other than a standard keyboard or pointing device;
7 a data analyzer, which produces statistics on both individuals and groups of patients.

At present, the main goal of CoRe is the rehabilitation of the logical-executive functions. The system offers different types of exercises that exploit textual (T), visual (V) and sound (S) stimuli. The implemented exercises with the specific type of stimuli used are the following:

- FIND THE CATEGORY (T&V): the patient has to choose, between