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A data mining approach to identify cognitive NeuroRehabilitation Range in Traumatic Brain Injury patients

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ABSTRACT

Cognitive rehabilitation (CR) treatment consists of hierarchically organized tasks that require repetitive use of impaired cognitive functions in a progressively more demanding sequence. Active monitoring of the progress of the subjects is therefore required, and the difficulty of the tasks must be progressively increased, always pushing the subjects to reach a goal just beyond what they can attain. There is an important lack of well-established criteria by which to identify the right tasks to propose to the patient. In this paper, the NeuroRehabilitation Range (NRR) is introduced as a means of identifying formal operational models. These are to provide the therapist with dynamic decision support information for assigning the most appropriate CR plan to each patient. Data mining techniques are used to build data-driven models for NRR. The Sectorized and Annotated Plane (SAP) is proposed as a visual tool by which to identify NRR, and two data-driven methods to build the SAP are introduced and compared. Application to a specific representative cognitive task is presented. The results obtained suggest that the current clinical hypothesis about NRR might be reconsidered. Prior knowledge in the area is taken into account to introduce the number of task executions and task performance into NRR models and a new model is proposed which outperforms the current clinical hypothesis. The NRR is introduced as a key concept to provide an operational model identifying when a patient is experiencing activities in his or her Zone of Proximal Development and, consequently, experiencing maximum improvement. For the first time, data collected through a CR platform has been used to find a model for the NRR.

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1. Introduction

Acquired Brain Injury (ABI) of either vascular or traumatic nature is one of the most important causes of neurological disabilities. According to the World Health Organization, Traumatic Brain Injury (TBI) is the leading cause of death and disability in children and young adults around the world and is a factor in nearly half of all trauma deaths (Walsh, Donal, Stephen, & Muldoon, 2012). In Europe, brain injuries from trauma are responsible for more years of disability than any other cause (Maas, Stocchetti, & Bullock, 2008).

Despite new techniques for early intervention and intensive ABI, both of which increase the survival rate, there is still no surgical or pharmacological treatment for the re-establishment of lost functions following brain injury. Cognitive rehabilitation (CR) is currently considered the therapeutic process for re-establishing functioning in everyday life (Pascual-Leone & et al., 2005). A typical CR program mainly provides exercises which require repetitive use of the impaired cognitive system in a progressively more demanding (Sohlberg, 2001) sequence of tasks. The rehabilitating impact of a task or exercise depends on the ratio between the skills of the treated patient and the challenges involved in the execution of the task itself. Thus, determining the correct training schedule requires a quite precise trade-off between *sufficient stimulation* and *sufficiently achievable* tasks, which is far from intuition, and is still an open issue, both empirically and theoretically (Green & Bavelier, 2005). It is difficult to identify this maximum effective level of stimulation and therapists use their expertise in daily practice, without precise guidelines on these issues.

In this work, the *NeuroRehabilitation Range (NRR)* is introduced as the conceptual framework to describe the degree of performance of a CR task that produces maximum rehabilitation effects. A data mining approach is used to induce an operational model for the NRR of CR tasks. The aim is to help create useful guidelines for CR therapists that can help them select the most appropriate tasks

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for each single patient at a given moment in their rehabilitation plan, as well as correctly to determine the most appropriate level of difficulty for the proposed task.

The Sectorized and Annotated Plane (SAP) is proposed here as a visual tool to find both the NRR and operational definitions to be used in real clinical practice.

Two data-driven methods to build the SAP are introduced and compared. One of them (DT-SAP) is based on a decision tree model, the other (Vis-SAP) on a visualization of available data that promotes model induction from a graphical representation. A quality criterion to assess NRR models is also introduced, based on the correct prediction ratio provided by the tool.

The performance of NRR model obtained with both DT-SAP and Vis-SAP approaches is evaluated and the advantages and drawbacks are analyzed over a real application.

Data comes from the PREVIRNEC© platform (Tormos, Garcia-Molina, Garcia Rudolph, & Roig, 2009) which contains rich data monitoring the CR process on real neurorehabilitation patients. The real performance of a representative cognitive task is analyzed under both approaches and discussed for a sample of patients following a CR treatment at Institut Guttmann (IG) hospital de Neurorehabilitació, Barcelona, Spain.

The structure of the paper is: Section 2 briefly presents the state of the art. Section 3 presents the IG conceptual framework for the research of NRR. Section 4 introduces the analysis methodology and Section 5 its application to a typical cognitive rehabilitation task in the proposed framework. Section 6 presents a discussion of the results obtained and Section 7 the conclusions and future lines of research.

2. State of the art

CR, as part of neuropsychological rehabilitation, tries to improve the deficits caused by ABI in daily living activities (Bernabeu & Roig, 1999) by retraining attention, memory, reasoning/problem solving, and executive functions. The plasticity of the central nervous system plays a central role (Pascual-Leone et al., 2005) in CR, based on therapeutic plans to stimulate that non-damaged neurons can modify their structure by learning from experience the damaged functions, through repetition (Luria, 1978). Plasticity may represent a surrogate marker of functional recovery, indicating behavioral change that is resistant to decay. In Kleim and Jones (2008) is suggested that a sufficient level of rehabilitation is likely to be required in order to get the subject *over the hump* i.e. repetition may be needed to obtain a sufficient level of improvement and brain reorganization for the patient to continue using the affected function outside of therapy and to achieve and maintain further functional gains. A great deal of research indicates that behavioral experience can enhance behavioral performance and optimize restorative brain plasticity after brain damage. Simply engaging a neural circuit in task performance is not sufficient to drive plasticity. Repetition of a newly learned (or relearned) behavior may be required to induce lasting neural changes. In fact, from the expert's point of view, there is a clear perception that the effectiveness of the task also depends on the replication, as Luria also asserts.

A typical CR program mainly provides exercises that require repetitive use of the impaired cognitive system in a progressively more demanding (Sohlberg, 2001) sequence of tasks. Each task targets a principal cognitive function and can be performed at different levels of difficulty, according to the response of the patient. The design of a CR program has become an essential issue for patient recovery.

As said before, the rehabilitating effect of a task or exercise depends on the ratio between the skills of the treated patient and the challenges involved in the execution of the task itself. The difficulty is related to the level of stimulation of cognitively involved functions; maximum activation occurs when the task is "*just barely too difficult*" (Green & Bavelier, 2005). If the task is too easy for the patient, or too hard, it appears to be less effective. Active monitoring of the subject's progress is therefore required to adapt the difficulty of the tasks to the potential capacities and progress of the subject, always pushing them to reach a goal just beyond what they can attain, but not too far. Thus, determining the correct training schedule requires a very precise trade-off between *sufficiently stimulating* and *sufficiently achievable* tasks, which is far from intuitive, and is still an open problem, both empirically and theoretically.

In the early 1930s, Vygotsky introduced the concept of Zone of Proximal Development (ZPD) (Vygotsky, 1934) in the field of child learning, being *the distance between the actual capacities of the child by himself and their potential capacities when being guided* (Vygotsky, 1978). In 1986, Cicerone and Tupper (1986) transferred ZPD ideas to the neurorehabilitation field by introducing the *zone of rehabilitation potential* (ZRP), i.e. the zone in which maximum recovery of cognitive functions might occur, provided that the proper help is given to the subject. They propose the use of ZPD as a guiding principle in CR. This zone is supposed to reflect the patient's region of potential restoration thanks to cognitive plasticity (Calero & Navarro, 2007). Current neurorehabilitation practice tries to design therapeutic plans that keep the subject working in this area during treatment. However, determining when the patient works in ZPD or not is still an open issue. Thus in most cases CR therapists design CR plans from scratch, determining clinical settings for specific patients based mainly on their own expertise. Each specific plan evolves according to each therapist's own criteria and evaluation of the patient's follow-up. There is as yet not enough in-field knowledge regarding which specific intervention (task or exercise assignation) is more appropriate to help CR therapists design their clinical therapeutic plans.

There is a common belief that CR is effective for TBI patients, based on a large number of studies and extensive clinical experience. Different statistical methodologies and predictive data mining methods have been applied to predict clinical outcomes of TBI rehabilitation (Rughani et al., 2010; Ji, Smith, Huynh,& Najarian, 2009; Pang et al., 2007; Segal et al., 2006; Brown et al., 2005; Rovlias & Kotsou, 2004; Andrews et al., 2002). Most of these studies focus on determining survival, predicting disability or the recovery of patients, and looking for the factors that better predict the patient's condition after an ABI. Q3

However, current knowledge about the factors that determine a favorable outcome is mainly empirical and the benefit of such interventions is still controversial (Ecri, 2011; Rohling, Faust, et al., 2009). The development of new tools to evaluate scientific evidence of such effectiveness will contribute to a better understanding of CR.

Several meta-analyses (Cicerone, Langenbahn, Braden, Malec, & Kalmar, 2011) identify structural limitations to find scientific evidence under classical approaches, related mainly to the existence of uncontrolled factors and the intrinsic difficulty of guaranteeing the sample heterogeneity. Classical approaches tend to generate evidence about effectiveness by comparing two or more interventions in selected and comparable groups. Determining the comparable groups relies on identifying the factors that influence recovery or chronicity, which should be controlled during the study, and these factors are unknown in neurorehabilitation. It seems that patient improvement might depend *inter alia* on the location of the injuries, cognitive profile, duration, and intensity of proposed treatments and their level of completion (Cicerone et al., 2011; Noreña et al., 2010; Whyte & Hart, 2003).

However, these seem to be only some of the determining factors and they cannot by themselves explain the overall phenomenon. Although these factors are considered in the design of rehabilitation

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