Published in final edited form as:

Neurorehabil Neural Repair. 2011 June ; 25(5 0): 3S–5S. doi:10.1177/1545968311402092.

Taking a Cognitive Neuroscience Approach to Neuro-rehabilitation

Maurizio Corbetta¹ and **Susan Fitzpatrick^{1,2}**

¹Washington University in St. Louis, St. Louis, Missouri, USA

²James S. McDonnell Foundation, St. Louis, Missouri, USA

Introduction

Stroke and other neurological injuries and diseases are a leading source of death and disability worldwide. In the US alone, 6 million people live with the consequences of stroke-related disability (<http://www.strokecenter.org/patients/stats.htm>). Improved medical care and increased public awareness of the need to respond swiftly to the signs of a possible stroke have reduced deaths. Similarly, individuals with traumatic brain injury and other insults disrupting brain function are also benefitting from improved acute care. The increasing numbers of survivors, many of whom must learn to cope with impairments and disabilities, are placing an increasing demand on the field of neurorehabilitation to do more to help individuals recover as much function and resume as much of their pre-stroke life as possible. Moreover, in industrialized countries, more and more people will need rehabilitation services as the general population grows older, and neurodegenerative conditions such as Alzheimer's or Parkinson's diseases become more prevalent. In developing countries there is a critical need for rehabilitation services, both neurological and non-neurological, especially in countries devastated by natural disasters, ongoing armed conflicts and wars. The need for rehabilitation is also increasing in countries where the use of personal motorized transportation is sharply increasing rates of traumatic injuries.

Not only social, but also scientific reasons are behind the likely expansion of the field of neurorehabilitation. Over the last three decades, a lot of studies have challenged the traditional notion that the brain cannot change once development is completed. There is now compelling evidence that the adult brain retains the ability to modify anatomical and functional connections as a result of learning or injuries. Some of these changes have been associated with recovery of function, especially when coupled with behavioral training. This is good news for rehabilitation as it provides strong scientific bases for the use of exercises and behavioral interventions to promote recovery after injuries of the nervous system.

However, these opportunities are overshadowed by a number of theoretical and practical issues that could lead to the marginalization of this field of medicine. Firstly, at present, neurorehabilitation is not built on solid scientific and theoretical foundations. Most current interventions have not been validated scientifically or are based on concepts of brain function that are outdated. Even when certain interventions have been shown to yield better clinical outcomes in randomized controlled trials, as in the case of admission to specialized stroke rehabilitation units leading to better outcomes than admission on general medicine

wards, it is not known what factors or combination of factors (specialized personnel, environment, intensity or type of therapy, multi-disciplinary approach) actually contribute to this effect.

Secondly, the efficacy of rehabilitation interventions is likely overestimated by the way rehabilitation teams operate. Typically, a therapist is responsible for both treating patients and evaluating their progress. This dual responsibility of therapists introduces bias, which would be unacceptable in a randomized-control study on the efficacy of a drug, and is compounded by institutional pressure to obtain positive results as third-party payers (insurances, national health agencies, etc) often 'weight' or make decisions regarding payments on indices related to patients' progress in therapy.

Thirdly, while more and more randomized, controlled trials are being performed, philosophically, the field of rehabilitation embraces a holistic view of disease processes in which physical and psychological deficits are considered jointly with their impact on everyday function and disability, individual by individual. Hence treatments and protocols are traditionally tailored to a single patient, often based on a therapist's or physician's own personal preference and experience, with little pressure to follow protocols in a consistent manner within or across patients. A final problem for the field is the steady decrease in health care funds, especially for those branches of medicine that do not rely on procedures or high-tech devices. This issue is most severe in the US where, as competition for funds increases, so does the pressure for each field of medicine to demonstrate the scientific value, efficacy, cost-effectiveness, and perceived social value of its interventions based on evidence.

We think that neurorehabilitation might be at a crossroads. One path may lead to the development of a mature clinical-behavioral science grounded in the principles of psychology and neuroscience. The other path is continuing the status quo, which, in the current environment of strong economic pressure, might lead to marginalization of the field. This trend would not only cause severe difficulties to hundreds of thousands of brain injury and stroke victims and their families, but would at the same time promote an already existing trend in social policies in which people with lesser economic means and new disabilities after brain injury would be left to their own destiny.

The McDonnell Project rationale

Cognitive neuroscience defines the study of the relationships between behavior and brain systems. This field has grown greatly over the last 20 years, and accordingly significant progress has been made in defining, at least in broad strokes, some of the computational, anatomical, and physiological principles that mediate specific behaviors. Much of what we now know, and are continuing to learn about the relationship between neural structure and observable behavior, has been derived from studying individuals with intact nervous systems in comparison to individuals with nervous system injuries. What has not yet happened, in any widespread systematic way, is using the knowledge of cognitive neuroscience to guide and inform interventions designed to minimize or reverse the impairments resulting from neural injury and disease.

The three manuscripts in this special issue are the first to appear from a series of workshop and panel activities organized by the Editors and supported by the James S. McDonnell Foundation. It is not a novel idea that Cognitive Neuroscience could serve as a foundational science for neurorehabilitation. Several excellent monographs and edited series have been recently published in this area, and private and public funding agencies have promoted programs to foster collaborations in these two areas. These domains of knowledge are conceptually adjacent to each other, and could profitably share concepts, principles, and even a common language. Cognitive neuroscience has matured into a scientific discipline with an internally consistent set of principles based on the idea that complex behavior can be described as a collection of simpler task processes using task analysis, and that these processes are implemented in specialized brain systems.

There are already several reference books for experts and academics, engaged predominantly in research, at the interface of cognitive neuroscience and rehabilitation. An excellent example is the book by Stuss, Winocur, and Robertson.¹ At the clinical end, there have been a number of books, predominantly written by neurologists and psychologists, to relate concepts in basic cognitive neuroscience with syndromes observed in behavioral neurology. An excellent example is the book by Feinberg and Farah.² From the neurological perspective an excellent monograph on the scientific basis of brain rehabilitation is the volume by the editor of *Neural Rehabilitation and Repair*, Bruce Dobkin.³

In the McDonnell Project, the editors' goal is not to produce yet another scholarly article or book primarily serving academic interests. Rather, we are interested in producing practical manuscripts written primarily for clinicians and clinical trainees in the field of neurorehabilitation (physiatrists, neurologists, neuropsychologists, therapists, nurses). We believe it is only by engaging a widening circle of hands-on practitioners and providing them with cogent summaries of what is relevant to clinical practice from the rapidly expanding and highly specialized research literature that it will be possible to move the fields of neurorehabilitation and cognitive neuroscience closer together.

Our project involved enumerating a set of functions. A function is defined as a set of behaviors that share a common goal. Seeing, walking, speaking, feeling your body, and reaching to grasp a desired object are examples of functions. These distinctions have ecological significance, but they also have clinical significance since when damaged these functions cause limitations in the performance of everyday activities and result in disability. Generally, the ability, or lack of ability, to carry out these functions is often the practical way rehabilitation professionals think about their patients. We deliberately chose not to divide functions based on neural systems but rather to invoke the interconnected neural systems that contribute to performance. The set of papers appearing here deal with "actions" of the upper limb and hand such as reaching, grasping, manipulating, and pointing.

Once the functions were determined, the next step was assembling a panel of experts for each function. The panels were charged with reviewing the current state of knowledge, and creating a framework whereby findings and principles from basic cognitive neuroscience could translate to clinical problems. The panels then began the task of generating a series of papers using a consensus-building process. A chair, appointed for each panel, accepted the

responsibility of shepherding the panel discussions and guiding the manuscript preparation to completion. Bridging levels of analysis from cognitive neuroscience to rehabilitation is important and necessary if we are to make progress building the science of neuro-rehabilitation, but it is also intellectually and practically difficult as anyone engaged in such efforts can attest.

It is important to note that the material summarized in the three papers does not probe the bleeding edge of scientific controversy but rather represents an expert view of the field. Each of the three papers represents a consensus document written by the panel. The chair of each panel is the first author on each of the three papers. The names of panel members are then listed in alphabetical order. Author order should not be used to interpret the degree to which any one individual contributed his or her expertise to the final documents, rather the papers represent the collected expertise. The papers are not heavily referenced; citations are limited to review articles or to book chapters that could serve as additional sources of information. The three panels of experts, and the papers that resulted from their discussions, are organized by three sub-topics (basic science, clinical diagnostics, and treatment interventions) within the overall topic of this special issue.

The Editors asked the first group of experts, (see Frey et al.,) to use a ***Computational-Anatomical-Physiological (CAP)*** framework for developing a set of principles about upper extremity actions. At the computational level (C), we consider: What is the goal of a certain function? How is this function performed at the behavioral level? What are the elementary behavioral components? We then consider how these processes are implemented in terms of ‘Anatomy’ (A) and ‘Physiology’ (P). What principles of anatomical organization have important behavioral consequences? What physiological signals underlie specific processes?

While we strive for simplicity, a certain degree of complexity is indispensable: we cannot treat effectively one of the most sophisticated and complicated machine of the universe without knowing some of its inner workings. Diagrams and figure are used across the papers to illustrate difficult concepts. Critically, as we go forward with this project, each CAP paper will contain up a small set of heuristics that distill what is most important from a cognitive neuroscience perspective and what is important to know about that specific function.

The second group of experts, (see Sathian et al.,) producing the second paper in the series, discussed the most common action disorders resulting from neurological damage.. The goal was twofold. First, to describe in a fairly practical way how to test a function based on the principles established in the first paper. A second goal is to give a description of the most common syndromes in light of the CAP framework, if possible; otherwise, to note relevant discrepancies. The general idea is to provide clinicians with a principled and scientifically oriented way to think about sensory, motor, and cognitive impairments in light of the current state of knowledge in cognitive neuroscience. For instance, what are the processes and neural systems that may be affected when someone is unable to grasp a desired object or turn a key in a lock after brain injury? How does one separate purely sensorimotor from higher level planning deficits?

The third group (see Pomeroy et al.,) of experts addressed current interventions. The emphasis was on evidence-based interventions: How do they relate to the theoretical principles stated in the CAP model? What experimental or clinical results support the use of one intervention over another? What is the best way to provide the interventions keeping in mind our understanding of dose, frequency, and intensity of treatment? What novel ideas or strategies of intervention could stem from the CAP model and its application to clinical problems?

By reading the three papers, a rehabilitation professional---physician, nurse, or therapist---can acquire a theoretical framework and some working principles on how to think about the behavioral deficits and underlying dysfunction of brain systems which an individual with brain injury may present with. Additionally, the practitioner will gain knowledge about how to prioritize interventions based on evidence-based principles. Ideally, we hope that rehabilitation professionals will use these manuscripts as a training tool and as a clinical practice reference. We also hope the manuscripts will encourage clinicians to think critically about the rationale, application, and assessment of established and novel interventions, as well as testing some of the predictions of the CAP model in their own patients. In the end, the success or failure of cognitive neuroscience will be measured by its potential for uncovering mechanisms of brain diseases and improving human brain health. Lastly, we hope that this project will stimulate the development of novel strategies either in the form of formal clinical trials or everyday practice. We believe there are both non-scientific and scientific ways to practice rehabilitation, and we hope through this effort to foster the latter approach.

Acknowledgments

The Editors and the Contributors thank Brent Dolezalek of the James S. McDonnell Foundation for his dedication and commitment to this project. Without the contribution of his organizational expertise the panel discussions and subsequent publications would not have succeeded.

References

1. Stuss, DT.; Winocur, G.; Robertson, IH., editors. Cognitive Neurorehabilitation: Evidence and Application. 2nd ed.. Cambridge University Press; Cambridge, Mass: 2008.
2. Feinberg, TE.; Farah, MJ., editors. Behavioral Neurology and Neuropsychology. 2nd ed.. McGraw-Hill; New York, NY: 2003.
3. Dobkin, BH. The Clinical Science of Neurologic Rehabilitation. 2nd ed.. Oxford University Press; New York, NY: 2003.
4. Frey SH, Fogassi L, Grafton S, et al. Neurological principles and rehabilitation of action disorders: computation, anatomy & physiology (CAP) model. *Neurorehabil Neural Repair*. In press.
5. Sathian K, Buxbaum LJ, Cohen LG, et al. Neurological principles and rehabilitation of action disorders: common clinical disorders. *Neurorehabil Neural Repair*. In press.
6. Pomeroy V, Aglioti SM, Mark VM, et al. Neurological principles and rehabilitation of action disorders: rehabilitation interventions. *Neurorehabil Neural Repair*. In press.