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Introduction

Constraint-Induced Movement therapy: Answers and questions after two decades of research

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Abstract. Constraint-Induced Movement therapy or CI therapy is a behavioral approach to neurorehabilitation based on a program of neuroscience experiments conducted with deafferented monkeys. Over the last 20 years, a large body of evidence has accumulated to support the efficacy of CI therapy for rehabilitating hemiparetic arm use in individuals with chronic stroke. Given the persuasive evidence for its efficacy to date, other research questions have risen to the forefront. How cost-effective is CI therapy? What are optimal training and other treatment parameters? What patient characteristics moderate the effects of CI therapy? The papers gathered in this special issue address many of these topics.

Constraint-Induced Movement therapy, also known as CI therapy [11], is a behavioral approach to neurorehabilitation derived from basic neuroscience [9,13]. Specifically, the approach is based on a program of research conducted by one of us (E. Taub) with monkeys after deafferentation of one forelimb that showed that nonuse of the deafferented forelimb is learned and can be overcome by the application of simple behavioral techniques (e.g., shaping [6,10] of impaired extremity use) [8]. The treatment for humans after neurological injury has three components: (a) repetitive, task-oriented training of the impaired extremity or function following shaping principles for several hours a day for 10 or 15 consecutive weekdays (depending on the severity of the initial deficit); (b) constraining patients to use the impaired extremity or function during waking hours over the course of treatment, sometimes by restraining the unimpaired extremity; and (c) applying a package of behavioral methods designed to transfer gains made in the clinical setting to the real-world [14].

Over the last 20 years, a large body of evidence has accumulated to support the efficacy of CI therapy for hemiparesis subsequent to chronic stroke (i.e., $>$ 1-year post-injury; e.g., see reviews by Taub and Uswatte [12], Sterr and Saunders in this issue). Evidence for efficacy includes results from: the initial small, randomized controlled trial (RCT) of CI therapy in individuals with mild-to-moderate upper-extremity hemiparesis secondary to chronic stroke [11]; a larger, placebo-controlled trial in individuals of the same chronicity and level of impairment [14]; a large, multi-site RCT in individuals with mild-to-moderate and moderate upper-extremity hemiparesis subsequent to subacute stroke (i.e., 3–9 months post-stroke) [18]. Positive findings regarding CI therapy after chronic stroke have also been

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obtained in several studies employing within-subjects control procedures (e.g. [1,4,7]) and numerous case studies (reviewed in [12]). Moreover, the most recent post-stroke clinical care guidelines [2] describe CI therapy as an intervention that has evidence of benefit for stroke survivors with mild-to-moderate upper-extremity hemiparesis.

Although virtually all of the CI therapy papers in the chronic stroke literature we know of report positive results [12], the range of effect sizes described is wide. A possible reason for this variation in outcomes is that some researchers used only one or two instead of all three components of the CI therapy treatment package. For example, studies employing only restraint of the unimpaired extremity (known as "forced-use" therapy; e.g. [17]) typically have much smaller effect sizes than those employing all three CI therapy components. Another possible explanation is that some researchers did not implement the CI therapy protocol properly. For example, van der Lee and co-workers [16] provided training of hemiparetic use in a group format using "housekeeping activities, handicrafts, and games [16]," which is likely to have resulted in much less intense training than is desirable for CI therapy [14]. To help address these problems, our laboratory has started holding semi-annual training workshops and is preparing a training manual for publication.

Given the robust evidence overall for the efficacy of CI therapy at this date, other research questions have risen to the forefront. How cost-effective is CI therapy? What are optimal training and other treatment parameters? What patient characteristics moderate the effects of CI therapy? In addition, an intervention with persuasive evidence of efficacy permits researchers to test questions of wide import for neurorehabilitation such as what are the effects of physical rehabilitation on the brain (e.g. [3]) and what pharmacological agents enhance the effects of physical rehabilitation (e.g. [5], Nadeau and Wu in this issue).

The papers gathered in this special issue address many of these topics. Mennemeyer, Taub, Uswatte, and Pearson report on return-to-work of family caregivers of CI therapy patients. Sterr and Saunders review the CI therapy literature with a focus on issues salient to the provision of CI therapy in clinical settings, such as the distribution and amount of training. Uswatte, Taub, Morris, Barman, and Crago present a set of preliminary studies examining the effect of type of training (i.e., shaping vs. repetitive task practice) and restraint of the unimpaired arm on CI therapy outcome. In separate papers, (a) Mark, Woods, Mennemeier, Abbas, and Taub and (b) Morris, Shaw, Mark, Uswatte, Barman, and Taub report on neuropsychological characteristics that moderate the effect of CI therapy in stroke and traumatic brain injury survivors, respectively. Bowman, Taub, Uswatte, Delgado, Bryson, Morris, McKay, and Mark, extending previous work from our laboratory examining the efficacy of CI therapy in patients with lower levels of impaired arm function than in the original studies [15], present a case report on a stroke survivor with virtually no active movement in the wrist and fingers of the hemiparetic arm. Nadeau and Wu discuss how CI therapy can be used as a "behavioral engine" to test pharmacological agents that might enhance the effect of physical rehabilitation techniques.

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