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Research report

Gross motor ability predicts response to upper extremity rehabilitation in chronic stroke

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ABSTRACT

The majority of rehabilitation research focuses on the comparative effectiveness of different interventions in groups of patients, while much less is currently known regarding individual factors that predict response to rehabilitation. In a recent article, the authors presented a prognostic model to identify the sensorimotor characteristics predictive of the extent of motor recovery after Constraint-Induced Movement (CI) therapy amongst individuals with chronic mild-to-moderate motor deficit using the enhanced probabilistic neural network (EPNN). This follow-up paper examines which participant characteristics are robust predictors of rehabilitation response irrespective of the training modality. To accomplish this, EPNN was first applied to predict treatment response amongst individuals who received a virtual-reality gaming intervention (utilizing the same enrollment criteria as the prior study). The combinations of predictors that yield high predictive validity for both therapies, using their respective datasets, were then identified. High predictive classification accuracy was achieved for both the gaming (94.7%) and combined datasets (94.5%). Though CI therapy employed primarily fine-motor training tasks and the gaming intervention emphasized gross-motor practice, larger improvements in gross motor function were observed within both datasets. Poorer gross motor ability at pre-treatment predicted better rehabilitation response in both the gaming and combined datasets. The conclusion of this research is that for individuals with chronic mild-to-moderate upper extremity hemiparesis, residual deficits in gross motor function are highly responsive to motor restorative interventions, irrespective of the modality of training.

1. Introduction

Motor restorative therapies aim to restore motor function by emphasizing practice with the more affected upper extremity while minimizing compensatory movement by the less affected upper extremity. Recently, the authors showed that this therapeutic approach may not be appropriate for all individuals who have sufficient motor ability to participate [1]. George et al. [1] presented a novel prognostic computational model to identify which baseline sensorimotor characteristics predicted the extent of motor recovery during Constraint-Induced Movement (CI) therapy, an established motor restorative intervention [2–5], employing the enhanced probabilistic neural network (EPNN) model of Ahmadlou and Adeli [6]. They found that the extent of motor restoration, as measured by the Wolf Motor Function Test (WMFT) [2,4,5,3], varied markedly among individuals and was generally poor amongst those with higher baseline ability.

The purpose of this follow-up research is to determine robust predictors of motor restoration irrespective of the type of motor training. This is accomplished by applying the aforementioned machine learning-based model to a very different treatment modality: motor training delivered at home via Recovery Rapids, a Kinect-based video game [7]. Like CI therapy, this motor restorative video game-based intervention involves high repetition practice with the more affected upper extremity for several hours per day over two weeks, progressive shaping of motor tasks, and an emphasis on carry-over of motor gains to daily activities [8,9]. There are several important differences between

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the two types of therapies, however. Recovery Rapids harnesses the benefits of a virtual world (i.e., no task set-up time) to dramatically increase task variability. As such, the client switches rapidly between different types of motor movements. In contrast, CI therapy utilizes blocked practice, in which the same task is practiced repeatedly for a period of about 10–20 min. Game-based therapy through Recovery Rapids also involves substantially more repetitions per time (> 1000 per hour on average), is largely delivered at home without direct therapist supervision, incorporates limited tactile feedback (participants do not touch objects), and distal (fine-motor) training comprises a smaller percentage of tasks (~30% versus > 90%).

The authors hypothesized that there are likely to be some commonalities in individual sensorimotor presentation that would make that individual a better candidate overall for motor restorative therapies, irrespective of therapeutic modality. Additionally, they expected that training-related factors would interact with individual characteristics to produce different patterns of poor versus good responders for the two different interventions. Specifically, they hypothesized that those with poorer function on the domain being trained would benefit more from the intervention. Consistent with this hypothesis, George et al. [1] found that those with relatively greater fine-motor ability at baseline benefited less from CI therapy, an intervention that targets fine motor tasks. In keeping with this hypothesis and the authors' prior findings, we hypothesized that those with poorer gross-motor performance at baseline would be better candidates for gaming therapy, as this approach does not provide as many fine-motor training opportunities. To test this hypothesis, the best combination of predictors from the prior paper will be compared with an identical analysis for the Recovery Rapids gaming therapy. To determine which elements of sensorimotor presentation predict more favorable outcome irrespective of therapeutic modality, the most predictive combinations of baseline sensorimotor ability for both gaming therapy and CI therapy will be identified.

This research aims to identify those individual characteristics at baseline that can predict response to two different motor restorative therapies. Improved predictions of treatment response based on a person's individual characteristics at baseline will enable therapists to devise cost-efficient personalized care plans with the goal of balancing restorative versus compensatory intervention approaches to maximize the motor functions of their patients.

2. Methodology

2.1. Participants

Participants were 19 individuals with chronic (> 6 months) mild to moderate upper extremity hemiparesis who had experienced a stroke of any etiology. All participants met the motor inclusion criteria utilized in the EXCITE trial of CI therapy [3], but were enrolled largely irrespective of cognitive or mobility status. The sample utilized in this analysis is thus more inclusive than in prior CI therapy trials. Those who were unable to provide informed consent, or who had received Botox treatment in the past 12 weeks were excluded. Inclusion criteria and recruitment approaches for this study were the same as those used in the earlier study by the authors [1]. See Table 1 for participant demographics.

Table 1
Demographic and clinical characteristics of 19 participants in gaming therapy.

Item	Number of case (Average)	Minimum	Maximum
Age	47.5	14.1	69.6
Sex	8 females	N/A	N/A
Chronicity (years)	N/A	0.55	5.34
Stroke affected side	8 left	N/A	N/A
Handedness	At least 6 right	N/A	N/A
Affected side was dominant	At least 4 participants	N/A	N/A

2.2. Intervention

The gaming therapy intervention was designed such that physical/occupational therapists manage patients in a consultative role with the majority of the motor practice occurring through Recovery Rapids, an in-home gaming rehabilitation system [7]. The gaming system utilizes the KinectOne™ sensor to capture particular therapeutic movements (gestures), each of which is tied to a game objective. Gestures include elbow flexion/extension, shoulder flexion with elbow extension, shoulder abduction, shoulder adduction, overhead reaching, forearm supination, grasp release, and wrist extension. The CI therapy principal of shaping (progressively increasing task difficulty as a person improves) is incorporated. In just one example, the user attempts to capture parachutes as they fall from above. An introductory difficulty level for this gesture may require only 30° of shoulder flexion. As a user demonstrates the capacity to perform more difficult movements, the software requires greater shoulder flexion, then increased concurrent elbow extension and forearm supination to accomplish the same game objective. See Fig. 1 for a depiction of the gaming environment (http://gamesthatmoveyou.com/). Carry-over of motor improvements to daily life is promoted through an interactive Motor Activity Log problem-solving module that occurs after each 15–20 min of the game play.

Five therapist/patient contact hours occurred over 4 home visits. The first session (2h) involved instruction in game play, customizing the game to the participant, establishing the treatment contract, and establishing the home program (target functional activities to accomplish daily). Thereafter, sessions focused on review of progress with the home program, modifying game customization as needed, and on "transfer package" elements that could not be readily addressed through the game [9,10]. "Transfer package" elements include reviewing the treatment contract, daily self-assessment of arm use, guided problem-solving to increase the use of the weaker upper extremity for activities of daily living, and collaboratively establishing a home program focused on functional task practice. Participants agreed to play Recovery Rapids for 30 h over a two-week period.

2.3. Outcome measures

Three outcome measures were utilized: the WMFT, the Brief Kinesthesia Test (BKT), and Touch Test Monofilaments (TM). The WMFT was utilized to assess the motor function of the upper limbs [2,4,5,3]. As in George et al. [1], the WMFT scores, recorded in seconds, were natural-log-transformed to account for the non-uniform interpretation of performance time improvement (i.e., an improvement from 5 s to 3 s is greater than an improvement from 105 to 103s). The BKT is a measure of error in guided reaching with visual occlusion considered to represent upper limb kinesthetic sense [11]. TM is sensitive to tactile impairment; it identifies the lightest "force" in grams perceived consistently by an individual on the index finger [12]. These same sensorimotor measures were used in the authors' earlier research [1] and are summarized in Table 2

Table 3 summarizes the collected patient data used for the prognostic computational EPNN model. From these data, there were 2 missing values corresponding to the somatosensory measures of only one participant. These were replaced using a simple regression analysis. Each participant was categorized based on their natural-log-transformed WMFT treatment change score as either a non-responder (> -0.15; class 1), moderate-responder (-0.15:-0.40; class 2), or best responder (< -0.40; class 3). Classification thresholds are consistent with the earlier research [1]. These categories are represented in the last column of Table 3. A histogram of WMFT change is shown in Fig. 2.

2.4. Sensitivity analysis and prognosis model

In order to identify the best method of classification, the authors