Active Finger Extension Predicts Outcomes After Constraint-Induced Movement Therapy for Individuals With Hemiparesis After Stroke

Stacy L. Fritz, PhD, PT; Kathye E. Light, PhD, PT; Tara S. Patterson, MSEd; Andrea L. Behrman, PhD, PT; Sandra B. Davis, PT

Background and Purpose—Constraint-induced movement therapy (CIMT) is a rehabilitative strategy used primarily with the post-stroke population to increase the functional use of the neurologically weaker upper extremity through massed practice while restraining the lesser involved upper extremity. Whereas research evidence supports CIMT, limited evidence exists regarding the characteristics of individuals who benefit most from this intervention. The goal of this study was to investigate the potential of 5 measures to predict functional CIMT outcomes.

Methods—A convenience sample of 55 individuals, >6 months after stroke, was recruited that met specific inclusion/exclusion criteria allowing for individuals whose upper extremity was mildly to severely involved. They participated in CIMT 6 hours per day. Pretest, post-test, and follow-up assessments were performed to assess the outcomes for the Wolf Motor Function Test (WMFT). The potential predictors were minimal motor criteria (active extension of the wrist and 3 fingers), active finger extension/grasp release, grip strength, Fugl–Meyer upper extremity motor score, and the Frenchay score. A step-wise regression analysis was used in which the potential predictors were entered in a linear regression model with simultaneous entry of the dependent variables’ pretest score as the covariate. Two regressions models were determined for the dependent variable, for immediate post-test, and for follow-up post-test.

Results—Finger extension was the only significant predictor of WMFT outcomes.

Conclusions—When using finger extension/grasp release as a predictor in the regression equations, one can predict individual’s follow-up scores for CIMT. This experiment provides the most comprehensive investigation of predictors of CIMT outcomes to date. (Stroke. 2005;36:1172-1177.)

Key Words: motor activity ■ physical therapy ■ rehabilitation ■ stroke outcome

Stroke is the most common disabling condition, with 30% to 66% of individuals losing functional ability in their more affected arm and hand.1 The need for innovative rehabilitation is clear because few well-researched and effective therapies are available to individuals after stroke. Constraint-induced movement therapy (CIMT), however, has shown great promise for individuals with hemiparesis. It encompasses a family of rehabilitation techniques having 2 main components: (1) constraint of the less involved upper extremity (UE), forcing the use of the more involved UE; and (2) massed practice of the more involved UE.2 CIMT results have been labeled the most promising evidence that motor recovery can occur in the hands of individuals after stroke that have some residual purposeful movement.3 Significant scientific evidence supports the efficacy of CIMT in improving function after stroke, but the functional characteristics of those who will benefit most from this therapy is unknown.2,4–8

In light of the recent attention of CIMT on the rehabilitation scene and the profound effect CIMT is beginning to have on rehabilitation strategies, scientists are charged with determining what characteristics are predictive of positive CIMT outcomes. The identification of clinical predictors for CIMT outcomes can help to target the individuals who benefit the most from this intervention.9 The aim of this study was to establish a predictive model for CIMT outcomes based on 5 potential measures.

Subjects and Methods

Participants
A convenience sample of 55 participants was recruited from 2 local CIMT projects. Table 1 presents the main participant characteristics. Participants signed an informed consent before participation in the institutional review board-approved study.

Inclusion and exclusion criteria are listed in Table 2. Participants were stratified according to their ability to meet minimal motor criteria to insure that the experiments contained participants of...
differing ability levels. Inclusion in the high-functioning group (n=32) required active movement of the wrist through at least 20 degrees of the flexion–extension range from a relaxed flexed position, and movement of at least 3 fingers 20 degrees at the metacarpal–phalangeal and interphalangeal joints (minimal motor criteria). Inclusion in the low-functioning group (n=23) required evidence of trace wrist extension and extension of 2 fingers from a fully flexed position but did not meet the criteria established in the high-functioning group.

### Procedure

After a pretest, participants received 2 weeks, 10 consecutive weekdays, of intensive treatment, 6 hours per day. For this period, the unaffected hand was immobilized in a padded mitt for 90% of their waking hours. The mitt was used at all times except when performing a minimal amount of agreed on activities (eg, bathroom activities, when UE used for an assistive device in walking, or when safety was compromised). The trainer and participants signed a behavioral contract establishing agreed on amounts of mitt use, task effort, activity logs, and home diaries. The participants were strongly encouraged to continue to use their weaker hand during activities throughout the day and while at home. After the 6 hours of intensive therapy, the participant returned home and maintained a diary documenting activities and mitt time use. During the weekends, there were no assigned tasks, but the participants were instructed to continue to wear their mitt and maintain a home diary.

During the 10 consecutive weekdays, participants received supervised task practice using their affected hand/arm. An activity log was kept by the trainer to demonstrate what tasks had been attempted and how the tasks were progressed during training. CIMT consisted of a set of tasks to be performed with the affected upper extremity, such as picking up pencils, moving beans from one container to another, stacking blocks, and using utensils. The treatment was focused on performance of frequent movement repetitions while performing functional activities. To remain challenging, as performance improved, tasks were increased in complexity and difficulty. The tasks were functional in nature but were modified to allow some success. The 10 days of training were followed by an immediate post-test and a 4- to 6-month follow-up post-test.

### Outcomes Measure

The Wolf Motor Function Test (WMFT), a commonly reported outcome measure in CIMT studies, was used. The WMFT has been used successfully as a CIMT outcome measure for several years.4–8 This test evaluates movement capability through a series of 15 timed tasks and 2 strength tasks. Only the timed tasks were used in this study. The tasks progress from joint specific to multi-joint movements.5,6 The reliability of the WMFT has been reported with interrater reliability established at r=0.93, as measured by an intraclass correlation coefficient.10 The WMFT outcome measure is reported as a mean of the affected task times minus the mean of the unaffected task times.

### Five Potential Predictors

#### Minimal Motor Criteria Level

CIMT appears to be effective in improving movement capabilities in a subset of ~20% to 25% of stroke survivors who meet minimal motor criteria.2,11 In this study we expanded selection criteria to include individuals that did not meet traditional minimal motor criteria level. Inclusion of this lower functioning group will aide in clarifying the necessity of these baseline criteria for positive outcomes with CIMT. Specifically, if minimal motor criteria are not a predictor, it may not be an appropriate determinant of CIMT participation.

#### Finger Extension/grasp Release

Grasp release is essential to functional movement of the hand. Individuals after stroke often have difficulty releasing an object possibly because of a flexor synergy that effectively limits isolation of joint movements out of synergy.12 Finger extension/grasp release was defined as the ability to actively release a mass flexion grasp as defined by Fugl–Meyer assessment.13

#### Grip Strength

Grip strength was used as a predictor in the regression model because of its prevalence in the literature as a measure of outcomes after stroke.14,15 and as a predictor of outcomes.3,16 Low grip strength is associated with disability, whereas there are strong relationships between mid-life measurements of grip strength to predictions of long-term survival.18

#### UE Fugl–Meyer Motor Score

The Fugl-Meyer Assessment measures percent recovery after stroke and provides an objective and quantifiable assessment of motor function.13 The UE Fugl–Meyer motor component is an assessment of ability to move in/out of synergy, reflexes, wrist stability, grasping ability, and coordination. The overall reliability is high (intraclass correlation coefficient of 0.96).13 This standardized assessment is also often used as a measure in stroke rehabilitation studies4–7 and has been shown to be predictive of dependency and functional level after stroke.9,19,20

### TABLE 2. Inclusion and Exclusion Criteria for Participants

#### Inclusion

- Diagnosis of at least 1 stroke and not >3 strokes on the same side of the brain
- Stroke at least 6 mo before study participation
- Follow simple instructions (score of 20 or higher on Mini-Mental)
- Sit independently without back or arm support for 5 min
- Stand with support of a straight cane, quad cane, or hemiwalker for 2 min
- Actively participate for 6 h of therapy without long rest/nap periods
- PROM of all UE motions of at least half the normal range

#### Exclusion

- Health problems that put the participant at significant risk for harm during the study
- Other neurologcal conditions
- Medications for spasticity
- Pain limiting participation in the study

### TABLE 1. Descriptive Characteristics of Participant Population

<table>
<thead>
<tr>
<th></th>
<th>No.</th>
<th>Min</th>
<th>Max</th>
<th>Median</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time since stroke, d</td>
<td>55</td>
<td>229</td>
<td>16060 (45 y)</td>
<td>940</td>
<td>1673</td>
<td>2378</td>
</tr>
<tr>
<td>Age, y</td>
<td>55</td>
<td>22</td>
<td>83</td>
<td>66</td>
<td>62.05</td>
<td>14.6</td>
</tr>
<tr>
<td>Side of stroke</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left brain stroke</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right brain stroke</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant side involved</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nondominant side involved</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Gender</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Female</td>
<td>22</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ambulatory status</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Ambulatory</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonambulatory</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Frenchay Activities Index

This survey was developed specifically for measuring disability and participation in life role activities for individuals with stroke. The item scores are totaled to determine the final score, which can range from 15 (inactive) to 60 (highly active). The Frenchay Activities Index was included as a predictor in the regression analysis as it is frequently cited for determining outcomes post-stroke. The relationship between the Frenchay score and the Frenchay Activities Index was assessed using a variance inflation factor.

Data Analysis

Demographic and clinical presentation characteristics of the study sample are described using the mean, median, and standard deviation for appropriate continuous variables, and using frequencies and percentages for categorical variables. For the intention-to-treat analysis, demographic and clinical characteristics were compared to determine differences that could result in a bias. These comparisons were made between those individuals who completed the follow-up post-test and those who did not. The continuous variables from the intention-to-treat analysis were analyzed using t-tests and categorical variables using chi-square tests or Fisher exact tests. All data were analyzed using an intention-to-treat approach in which the pretest scores were used as the follow-up post-test scores for those participants that did not return for the follow-up.

Results

Power Analysis

A post-hoc power analysis was conducted to determine the power for the sample size (n=55). The effect size (f^2) for the WMFT immediate post-test and follow-up post-test were 3.67 and 2.82. Using these effect sizes, the sample size of 55 participants at an α=0.05, for 5 predictors, met an average power level β=1.0. This strong power can be attributed primarily to the presence of the covariate in the model. Table 3 provides the descriptive statistics of the independent variables.

Intention-to-Treat Analysis

An intention-to-treat analysis was used because of the significant pre-test differences apparent between the group that completed the follow-up post-test and the group that did not. Nine participants did not return for the follow-up post-test evaluation and, therefore, their pretest score was used as the follow-up post-test measure. Three of the independent variables demonstrated significant differences between the individuals who returned for the follow-up post-test and those who did not return. Individuals who dropped out showed significantly lower ability levels (Table 4); therefore, intention-to-treat analysis was essential to avoid bias in the results.

Multiple Regression Modeling

The potential predictors were entered into two linear multiple regression models with stepwise entry using the [ln]WMFT immediate post-test, or follow-up post-test, as the dependent variable and entry of the WMFT prescore as the covariate. The only significant predictor for both equations was finger extension/grasp release, all other variables were removed during the regression analysis. Including the covariate, the immediate post-test model accounted for 0.786 of the variance in [ln]WMFT, and 0.738 of the variance in WMFT at follow-up post-test. The probability values for all the independent variables are listed in Table 5. The final regression equations are as follows.
The largest value of the variance inflation factors was 1.7, indicating that multicollinearity among the predictors did not unduly influence the regression estimates. On visual examination of the histogram, the residuals appeared to be normally distributed. Presence of outliers was assessed using Jackknife residuals; residuals were considered outliers. The sample contained 2 outliers for the WMFT model. The influence and accuracy of these data points were assessed and they remained in the model. These post-hoc regression diagnostics results suggested that the regression analysis was appropriate.

### Discussion

#### Multiple Regression Modeling

The goal of this study was to investigate the potential of 5 measures to predict functional outcome for CIMT. Finger extension/grasp release significantly predicted function of the affected UE, according to the WMFT. Finger extension/grasp release showed predictive capability at immediate post-treatment and at follow-up. The predictive capability of finger extension/grasp release is logical because of its role in the functional use of a hand. This measure, although related to minimal motor criteria, does not include the requirements of wrist extension. In this sample, minimal motor criteria did not predict outcomes for the WMFT. This finding is important since the primary screening criteria used for the majority of CIMT studies is an individual’s ability to meet minimal motor criteria. Establishing minimal motor criteria has been an advantageous and an appropriate screening technique for

### TABLE 4.  \( t \) Test for Difference Across Continuous Independent Variables and \( \chi^2 \) and Fisher Exact Test for the Differences Across Categorical Independent Variables Between Those Participants Who Completed the Follow-up Evaluation and Those Who Did Not Complete the Evaluation

<table>
<thead>
<tr>
<th>Independent Variables (Pretest Scores)</th>
<th>Drop-outs</th>
<th>Completed</th>
<th>( t ) Test (Sig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip strength</td>
<td>3.08 (4.82)</td>
<td>9.86 (7.33)</td>
<td>0.003*</td>
</tr>
<tr>
<td>Fugl-Meyer UE motor</td>
<td>29.22 (6.04)</td>
<td>36.46 (11.86)</td>
<td>0.013*</td>
</tr>
<tr>
<td>Frenchay</td>
<td>29.78 (6.18)</td>
<td>38.48 (7.43)</td>
<td>0.003*</td>
</tr>
<tr>
<td>Categorical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimal motor criteria level</td>
<td>High</td>
<td>3</td>
<td>29 0.098</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Fugl-Meyer finger extension</td>
<td>0</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>5</td>
<td>22 0.113 na</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>14</td>
</tr>
</tbody>
</table>

* Significant differences in independent variables for drop-outs vs completers of the follow-up.

### TABLE 5. Adjusted \( R^2 \) for WMFT Models, \( B \) Weights, \( P \) for all the Predictors and Confidence Intervals for the Significant Predictors

<table>
<thead>
<tr>
<th>WMFT Models</th>
<th>Immediate Post-test</th>
<th>Follow-up Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.786</td>
<td>0.738</td>
</tr>
<tr>
<td>F (Sig)</td>
<td>100.099 (0.000)</td>
<td>77.037 (0.000)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>( B )</th>
<th>( P ) (CI)</th>
<th>( B )</th>
<th>( P ) (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covariate (WMFT prescore)</td>
<td>0.036</td>
<td>0.000 (0.026, 0.043)</td>
<td>0.033</td>
<td>0.000 (0.025, 0.041)</td>
</tr>
<tr>
<td>Minimal motor criteria level</td>
<td>0.041</td>
<td>0.693</td>
<td>0.007</td>
<td>0.949</td>
</tr>
<tr>
<td>Finger extension</td>
<td>-0.410</td>
<td>0.027 (-0.771, -0.048)</td>
<td>-0.402</td>
<td>0.04 (-0.785, -0.020)</td>
</tr>
<tr>
<td>Grip strength</td>
<td>-0.048</td>
<td>0.570</td>
<td>-0.063</td>
<td>0.504</td>
</tr>
<tr>
<td>UE Fugl-Meyer motor score</td>
<td>-0.126</td>
<td>0.214</td>
<td>-0.185</td>
<td>0.098</td>
</tr>
<tr>
<td>Frenchay</td>
<td>0.064</td>
<td>0.376</td>
<td>-0.032</td>
<td>0.687</td>
</tr>
<tr>
<td>Constant</td>
<td>1.608</td>
<td>0.000 (0.956, 2.261)</td>
<td>1.804</td>
<td>0.000 (1.113, 2.494)</td>
</tr>
</tbody>
</table>
Statistical Analysis Discussion

Including the pretest scores as a covariate in the models may be questioned because it increases complexity and practicality of using the model. Specifically, a baseline test is required to use the regression equations for prediction of outcomes for CIMT. The use of the covariate, however, was essential to form accurate regression models. The pretest score for the WMFT was used as a covariate to statistically control for differences that existed between participants before treatment.

Controversy exists surrounding the use of stepwise regression. Although stepwise methods are frequently used in behavioral research, Thompson argues that severe limitations exist with this method. For example, he claims that incorrect degrees of freedom are often used by the statistical software. This misuse, however, is accentuated when a large number of predictors are “thrown” into the model. In this study, restricting the stepwise equation to 5 predictors decreases the chance of a type I error. Another limitation is that stepwise regression tends to capitalize on sampling error. In other words, if your sample is not representative, your results will not be replicable. Every effort was made for the sample to contain a diverse population of individuals with stroke across descriptive and functional categories. Many recently published articles include stepwise regression for predictive modeling. Using stepwise allows for the most efficient and usable models. If simultaneous entry was used instead, it would result in inclusion of nonsignificant predictors in the regression equations. This would cause greater clinical demand to measure all the predictors to use the model.

The goal of this study was to establish usable models, not extensive or comprehensive models. Whereas detailed models serve a function, they are less readily used and have little more predictive capability than simple models. Other predictive variables could have been included in this model, potentially making it more inclusive. For example, cognitive function, participants’ social networks, or motivational variables may have increased the predictive capability of these models. In addition, modern imaging techniques could have been included to identify type or location of lesion, because they are valuable in prediction of stroke outcomes. These additional predictors would add to the complexity of the model, making it more difficult to use and clinically less practical while potentially adding little strength to the model.

Summary

Limited evidence existed regarding the specific characteristics of individuals who benefit most from CIMT. In this study, significant predictive ability was discovered with finger extension/grasp release. This item, when used in the regression equations along with the covariate, can predict an
individual’s score on the dependent measure. Selection criteria for participation need to be carefully examined to ensure proper inclusion in CIMT studies. Further substantiation of these findings in larger and more diverse samples is warranted to meet the urgent need of determining the appropriate candidates for CIMT. This experiment provides the most comprehensive investigation of predictors of CIMT outcomes to date providing a foundation for the formation of new inclusion criteria for CIMT studies.

Acknowledgments
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References
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