

# Effects of robotic-aided rehabilitation on recovery of upper extremity function in chronic stroke: a single case study

NANCY A. FLINN, Sister Kenny Institute, and The College of St. Catherine, St. Paul, Minneapolis, MN  
JENNIFER L. SMITH, CHRISTOPHER J. TRIPP, MATTHEW W. WHITE, Sister Kenny Research Center, and Sister Kenny Institute, Minneapolis, MN

**ABSTRACT:** *The objective of the study was to examine the results of robotic therapy in a single client.*

*A 48-year-old female client 15 months post-stroke, with right hemiparesis, received robotic therapy as an outpatient in a large Midwestern rehabilitation hospital. Robotic therapy was provided three times a week for 6 weeks. Robotic therapy consisted of goal-directed, robotic-aided reaching tasks to exercise the hemiparetic shoulder and elbow. No other therapeutic intervention for the affected upper extremity was provided during the study or 3 months follow-up period. The outcome measures included the Fugl-Meyer, graded Wolf motor function test (GWMFT), motor activity log, active range of motion and Canadian occupational performance measure.*

*The participant made gains in active movement; performance; and satisfaction of functional tasks, GWMFT and functional use.*

*Limitations involved in this study relate to the generalizability of the sample size, effect of medications, expense of robotic technologies and the impact of aphasia. Future research should incorporate functional use training along with robotic therapy.*  
Copyright © 2009 John Wiley & Sons, Ltd.

**Key words:** case study research, robotic arm, stroke rehabilitation

## Introduction

According to the National Stroke Association and Kilmer (2008), stroke is a leading cause of disability in the United States. Over 4 million people in the

United States today have survived a stroke (Bonifer et al., 2005). Functional disability resulting from stroke challenges survivors, their caregivers and rehabilitation professionals.

Robot-aided neurorehabilitation for stroke recovery has been emerging in the literature over the past decade. The use of robotics in the rehabilitation of the hemiplegic upper extremity (UE) in stroke survivors has been supported by a series of research projects (Volpe et al., 1999, 2003; Fasoli et al., 2003, 2004; Ferraro et al., 2003). These studies consistently demonstrated significant improvements in muscle strength and coordination in the muscles of the shoulder and elbow in stroke survivors with deficits in these areas. There is some evidence that robotic therapy demonstrates larger changes in strength and active range of motion (AROM) than neurodevelopmental treatment (Lum et al., 2002).

Another innovative treatment approach is constraint-induced movement treatment (CIMT), which has been shown to improve speed of performance and movement of the UE, even up to 20 years post-stroke (Taub and Wolf, 1997; Taub et al., 1999; Wolf et al., 2006). This rehabilitation facility started offering this form of treatment in 2001 to our chronic stroke patient population. However, we found that many patients did not have the 45 degrees of shoulder abduction or flexion, and 10 degrees of elbow extension required for success in CIMT, nor did they have the wrist or hand function, and therefore could not participate in this form of treatment (Wolf et al., 2006). This therapy team decided to explore the use of robotic therapy to expand the pool of patients who could benefit from CIMT by increasing the proximal motion and strength needed to participate in treatment. The researchers also recognized that the use of robotics offered another treatment option for those that were considered to have plateaued in motor recovery of the UE.

While early studies on robotic-aided neuromuscular re-education were promising, there are a number of questions that have not yet been answered. This case study was designed to support the current evidence of the effect of robotic treatment on muscle function return relative to one participant. It also investigates the relationship of robotic-aided treatment on return of spontaneous, functional use of the UE.

## Methods

Our participant was a 48-year-old female who had an ischaemic stroke. She was hospitalized 1 week in a general hospital before being transferred to a regional inpatient rehabilitation unit. She spent 4 weeks participating in a comprehensive rehabilitation programme before returning home with her husband. In the 15 months since then, she had intermittently participated in outpatient physical, occupational and speech therapy services. At the time of this treatment, she was not involved in any other therapies.

She continued to demonstrate dense right hemiplegia, an inferior and anterior shoulder subluxation with mild shoulder hand syndrome. Her shoulder hand syndrome symptoms included pain with movement, especially active or passive shoulder range beyond 40 degrees of shoulder flexion. The participant presented with hypertonicity, as observed by an experienced, registered occupational therapist (OT) during pre-testing. Right-sided inattention/neglect was also apparent as a result of the stroke. She had aphasia, expressive more apparent than receptive. Her husband, however, was able to understand her more easily, and relayed her experience to the researchers. He attended all treatment and evaluation sessions, and would paraphrase or interpret her statements, and then she would confirm or disagree with them. Her husband reported that by her participation in the study, she hoped to gain more functional use of her arm during daily life activities.

In 2005, this facility chose the InMotion2 robot by Interactive Motion Technologies, Inc. because of the studies suggesting efficacy in stroke recovery at that time (Volpe et al., 1999, 2003; Fasoli et al., 2003, 2004; Ferraro et al., 2003), and because it was a commercially available product. A picture of the robot in use can be seen in Figure 1.



FIGURE 1: Photo of registered occupational therapist explaining the InMotion2 treatment module to a staff member.

The InMotion2 allowed a participant to practice reaching motions in a gravity-reduced horizontal plane. The motions require shoulder flexion and extension, internal and external rotation and elbow flexion and extension. The set-up for the participant is relatively quick. The participant is seated at a desk and places his or her forearm into a trough. The participant looks at a computer screen and attempts to move the arm towards a target. The device gives guidance when needed in order to make each attempted movement successful.

### *Instrumentation*

Data were collected from the participant with help from an experienced OT not providing the robotic interventions. The OT was aware of the participant's participation in robotic interventions, but was not familiar with the device or treatment protocols. Assessments were administered according to standardized guidelines. Because all measurements were done by the same therapist, we were most concerned about intra-rater reliability when evaluating measurement tools. The participant performed three testing sessions, a pre-testing session, a discharge and a final testing session completed 3 months after the completion of treatment to determine the longer-term effect of the intervention. Each visit required approximately 2 h to complete the assessment battery.

AROM was assessed using standard protocol (Radomski and Trombly Latham, 2008a). This is a widely used measure, and intra-rater reliability has been shown to be fair to good, at  $r = 0.41$ – $0.66$  for shoulder internal and external rotation (Radomski and Trombly Latham, 2008a).

The GWMFT was used for this study was designed to be used with individuals with more severe UE involvement. This version eliminated fine motor function tasks, added tasks focused on supination and pronation and decreased the gross grasp activities. Inter-rater reliability has been established at  $r = 0.92$  (Bonifer and Anderson, 2003).

The Fugl-Meyer assessment of motor recovery after stroke (Fugl-Meyer et al., 1975) as an evaluation tool identifies specific areas of weakness in the involved UE, as well as quantifying abnormal movement patterns. Intra-rater reliability for this measure is good for the UE sub-test, at  $r = 0.96$  (Radomski and Trombly Latham, 2008b).

The motor activity log (MAL) was another assessment tool used in the battery. This is a structured interview developed to measure the actual use of the involved arm in stroke survivors in a variety of daily activities (Taub et al., 1993; Uswatte and Taub, 1999). In this study, only the 'how much' portion of the measure was used, the amount of use of the involved arm in 30 routine daily activities. The MAL has been shown to have a test-retest reliability of  $r < 0.91$ , and inter-rater reliability between participants and caregiver of ICC = 0.90 (Uswatte and Taub, 1999; Taub et al., 2006).

The Canadian occupational performance measure (COPM) (Law et al., 1998) is a semi-structured interview used to identify up to five participant goals, and their perspective on the performance and satisfaction with performance of those goals. Participants rank their five most important problems and use a visual analogue scale to rate both how well they perform those tasks and how satisfied they are with that performance, on a scale of 1–10. Test–retest reliability has been established for the COPM for stroke survivors, with  $r = 0.89$  for performance, and  $r = 0.88$  for satisfaction (Cup et al., 2003).

These assessments evaluated the strengthening of the involved right UE that occurred as a result of the robotic device. Further, they looked at the incorporation of the strengthened UE in daily activities. The purpose of this unique test battery was to examine a projected link between intervention and improvement in functional use of the affected limb.

### *Intervention*

This study intervention involved treatment using the robotic device for the affected UE. The participant received a total of 18 h of robotic treatment on the device. The treatment was provided in 1 h sessions, three times a week for 6 weeks, totalling 18 1-h sessions. A registered OT set the participant up on the robotic arm for each 1-h session, and monitored the participant throughout the intervention. During the intervention, the participant was seated at a table with the paretic arm placed in an arm support attached to the robot arm effector (i.e. the forearm and wrist support). The participant's trunk movement was restrained by a five-point seatbelt. The participant was asked to perform goal-directed, planar reaching tasks that emphasized shoulder and elbow movements. As the participant attempted to move the robotic arm towards designated targets, the computer screen in front of her provided visual feedback of the target location and movement of the robot handle. The robot offered as-needed assistance when the participant was unable to reach targets independently, much like a therapist provides hand-over-hand assistance during conventional therapy (Krebs et al., 1998). If the participant was unable to move her arm towards a given target, the robot would assist her in the attempt to move much like providing passive range of motion. If the individual could initiate but not complete a reach, the robot was compliant to the person's movement attempts, and gave active assist as needed (Krebs et al., 2008).

The participant was required to reach or move the robotic arm towards a blinking target shown on the monitor, and then back to the centre of the screen. This target moved in a clock-like fashion. At each session, the participant's goal was to achieve approximately 1000 movements. This number of movements and intensity of treatment is consistent with protocols done in previous UE robotic studies using the InMotion2 robotic arm (Fasoli et al., 2003). No other treatment was given during the course of the study.

**Results**

The assessment battery confirmed some progress after 6 weeks of robotic therapy intervention. Results can be referenced in Tables 1 and 2. Outcome data are also depicted in Figures 2 and 3. Fugl-Meyer, and COPM results are shown in Figure 2. GWMFT results are shown in Figure 3.

The Fugl-Meyer assessment of motor recovery after stroke total score improved 8 points within the treatment period, and the progress was maintained 3 months later. This improved score indicates the participant was able to complete target movement patterns better following intervention, and the progress was maintained following 3 months of no robotic intervention.

The MAL indicated minimally increased functional use after 6 weeks, and the improvement was maintained. The average score remained the same; however, the activities she participated in varied slightly.

The GWMFT improved by a median score of 51 s, and at the 3-month follow-up maintained a median score improvement of 44 s. The median score improvement in seconds indicates an increase in speed of performance. At

TABLE 1: Participant outcome results

Outcome assessment periods	Fugl-Meyer	Motor activity log (MAL)	Graded Wolf motor function test (GWMFT)	Canadian occupational performance measure (COPM) performance	COPM satisfaction
Pre-test	20	0.14	115	5.4	5.4
Discharge	28	0.16	64	6.2	6.4
Pre-test to discharge	8	0.02	51	0.8	1.0
Follow-up	28	0.16	71	7.9	5.9
Pre-test to follow-up	8	0.02	44	2.5	0.5

Note: This chart depicts the participant’s right upper extremity coordination and functional ability as measured by the individual outcome assessment tools used. Fugl-Meyer is reported as total score. MAL is reported in mean average. GWMFT is reported in total number of seconds. COPM performance and satisfaction are reported in mean average. The pre-test to discharge and pre-test to follow-up rows give the performance change within that interval.

15570703, 2009, 3-4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/oti.280, Wiley Online Library on [12/04/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

AROM	Pre-test	Discharge	Pre-test to discharge change	Follow-up	Discharge to follow-up changes
Shoulder flexion	5	5	0	5	0
Shoulder abduction	35	105	70	105	0
External rotation	-25	65	90	0 (neutral)	-65
Internal rotation	90	90	0	90	0
Elbow flexion	85	82	-3	52	-30
Elbow extension	-20	0	20	0	0
Pronation	90	85	-5	75	-10
Supination	65	85	20	90	5
Wrist flexion	0	30	30	30	0
Wrist extension	0	15	15	15	0

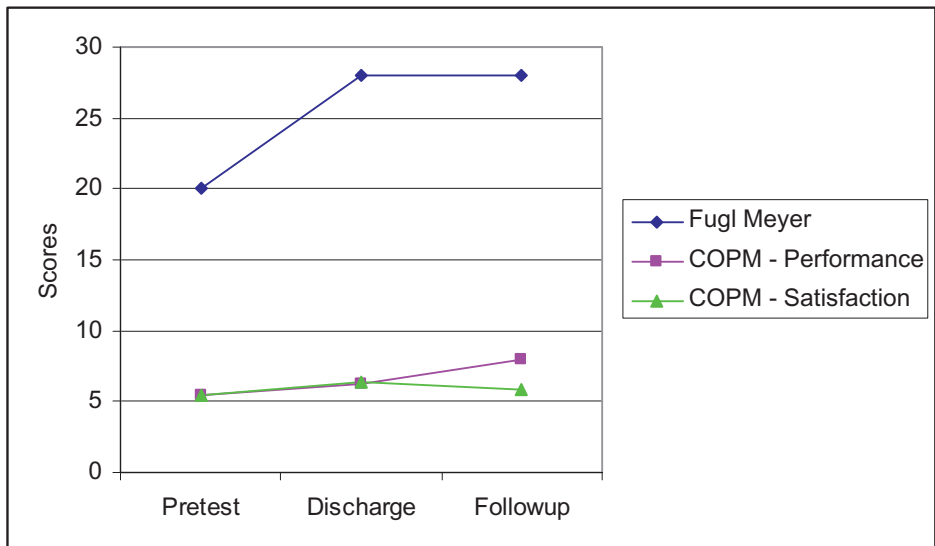


FIGURE 2: Outcome results of the Fugl-Meyer, motor activity log and Canadian occupational performance measure.

discharge and follow-up, the participant was also able to complete tasks that she had not been able to do at the initial assessment, including extending her elbow while pushing a weight and lifting a basket. At the follow-up, she was able to complete two tasks she had not been able to do before, including extending her elbow in a horizontal plane without a weight, and picking up and releasing an object. She had lost the ability to complete some other tasks at the follow-up,

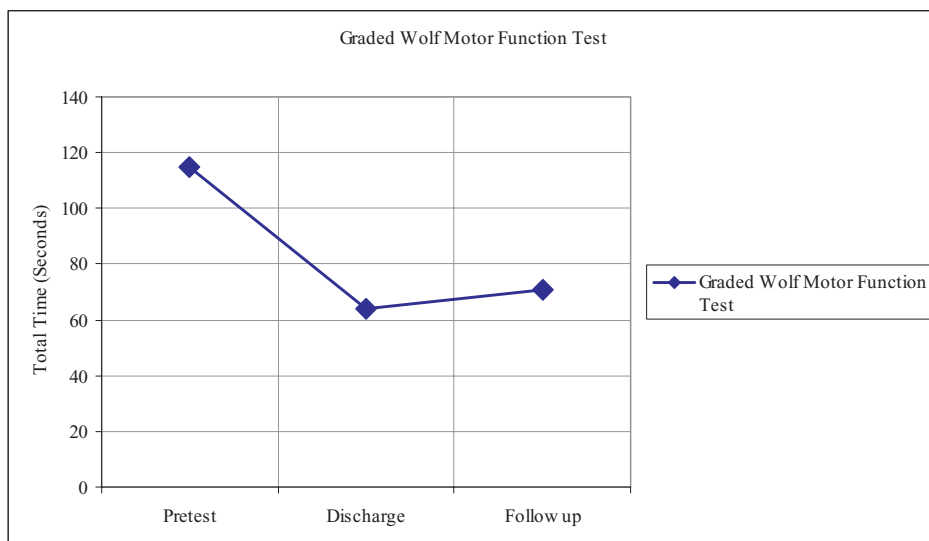


FIGURE 3: Outcome results of the graded Wolf motor function test.

including lifting a pen and demonstrating control in supination and pronation with the forearm supported.

No task-related training was incorporated as part of this study, but she used the motor control gained within the study functionally for tasks for which she was highly motivated. She and her husband had identified five task-related goals, which she was highly motivated to achieve, as part of the COPM assessment during the pre-test.

On the COPM, the participant had improved functional performance in the five goal areas she identified during the initial assessment, and made more improvement between discharge and 3-month follow-up. She experienced improved satisfaction with her performance of these five tasks between pre-test and discharge, and while she did not maintain all of these gains, there was improved satisfaction at follow-up over her pre-test scores.

At the post-test, the participant demonstrated improved AROM in shoulder abduction, external rotation, elbow extension and wrist flexion and extension. Of these, some of the shoulder external rotation and elbow extension AROM gains were not maintained at the time of the follow-up testing. The participant also reported decreases in pain, and stiffness over the course of the study.

Interestingly, her husband reported that the participant had improved self-esteem during her participation in the robotic-aided intervention. Her husband spoke briefly about how depressed she had been with her physical appearance and functional abilities before her participation in the study. During the study,



her mood and disposition improved as she was able to see her arm move again, aided by the robot.

## Discussion

As noted, this study looked at the changes in function related to the use of robotics. The results show improvements in COPM and MAL scores from pre-test to follow-up (see Table 1). Although modest, the participant perceived improvement in task performance. This may account for the mentioned participant's improvements in mood and disposition. It is not altogether clear whether this is due solely to the robotic intervention, or the increased engagement and attention as a part of the study, to her affected limb. The findings of improved motor recovery based on the changes on the Fugl-Meyer scores are consistent with findings in previous studies using robotics (Fasoli et al., 2003). A surprising finding was that the improvements at proximal joints from the robotic intervention translated into modest improvements distally at discharge according to AROM measurements. These gains were also maintained at the 3-month follow-up. Wrist flexion and extension, and supination AROM values all increased from pre- to post-test. Using this version of the InMotion2 robotic arm reaching to targets does not offer opportunity for distal engagement in any of these movements. This reinforces the notion that proximal control provides a foundation for distal mobility and function.

Our case study participant made improvements in function, as measured by the MAL. According to the participant's raw MAL scores, she has been using her affected limb more functionally than she did prior to the study. Our participant did perceive improvement from pre-test to discharge. For participants with this level of UE paralysis, it may be that the MAL items are too limited to reveal statistically significant changes.

In another measure used in our study, the COPM, the participant identified improved functional performance. This individualized measure of improvement of occupational performance may be a better indicator of change in function, or perceived change in function.

### *Implications for occupational therapy practice*

These findings contribute to the scientific knowledge already available on rehabilitation of the UE after stroke and robotic interventions.

This research confirms a relationship between component skills such as AROM and spontaneous functional use. These findings of small functional improvements in the face of larger improvements in AROM suggest the need to combine the robotic intervention with intense functional training to complement the motor recovery gain. Previous research has shown that to make lasting changes in functional use, functional use has to be incorporated into treatment

and daily routines. In addition, this participant's hand function did not improve enough to enable reasonable attempts at use on a regular basis. This speaks to the need for some form of functional control of the hand and fingers in order to promote significant changes in lifestyle after stroke.

### *Limitations*

There are a few limitations involved in this study. Although this case study supports previous research, it is only one individual. The participant did present with typical impairments following an ischaemic stroke; however, sample size makes it difficult to generalize the results to other stroke survivors, clinics or a larger geographical area.

In this study, two self-report measures were used to look at the participant's perception of functional use. The participant's aphasia limited her verbal participation in these measures.

This study did not control for medication changes, or other types of therapeutic interventions during the study period. Although this individual did not experience any medication changes during the intervention period, she did participate in an intensive speech therapy programme.

A limitation to the integration of technologies such as robotics to the standard rehabilitation protocol for UE treatment after stroke could be the expense. Although the product used in this study is commercially available, it may be cost prohibitive to some rehabilitation centres.

### *Future research*

There are several possibilities for future research. First, wrist and hand movement may need to be added to robotic training. Second, it may also suggest that increased daily use of the arm maintains function, and if the client is not able to incorporate the arm into enough daily activities, they are not able to perform enough targeted exercise to maintain the increased strength. Future research should address the long-term effects of robotic therapies.

Future research should examine whether the addition of the forced use or incorporation of instruction in functional use would lead to greater changes in functional use of the hemiparetic limb, when using robotic therapy. Several studies have demonstrated increased movement as a result of repetitive, goal-directed robotic therapy in persons with chronic motor impairments caused by stroke. However, very little work has been done to identify whether, and to what extent, the use of robotics may lead to more functionally useful limbs and significant changes in client daily activities, for example, increased independence or quality of life in persons with chronic motor impairments caused by stroke. Initial studies by Krebs et al. (1998) have established improvements in motor function in the UE, but have not demonstrated that this improved motor function alone will translate to improved functional use. This is an area in which

our findings support the need for larger studies looking to find evidence of this transfer of improved movement to improved functional skill.

## Conclusion

Robotic therapy was successful in gaining active movement in the involved UE in a stroke survivor with chronic motor deficits. The participant also made small gains in functional use. This illustrates that while improvement in motor function is a prerequisite for improvement in functional use of the involved arm after stroke, improvement in motor function does not necessarily translate to functional use.

## Acknowledgements

The researchers would like to thank the Sister Kenny Rehabilitation Institute Foundation for funding this project. The researchers would also like to extend their appreciation to the Sister Kenny Research Center for their support of this research (Sister Kenny Foundation grant number 05-S13).

## References

- Bonifer N, Anderson KM (2003). Application of constraint-induced movement therapy for an individual with severe chronic upper extremity hemiplegia. *Physical Therapy* 83: 384–398.
- Bonifer N, Anderson KM, Arciniegas DB (2005). Constraint-induced movement therapy after stroke: efficacy for patients with minimal upper-extremity motor ability. *Archives of Physical Medicine and Rehabilitation* 86: 1867–1873.
- Cup EH, Scholte-op-Reimer WJ, Thijssen MC, van Kuyk-Minis MA (2003). Reliability and validity of the Canadian occupational performance measure in stroke patients. *Clinical Rehabilitation* 17: 402–409.
- Fasoli SE, Krebs HI, Stein J, Frontera WR, Hogan N (2003). Effects of robotic therapy on motor impairment and recovery in chronic stroke. *Archives of Physical Medicine and Rehabilitation* 84: 477–482.
- Fasoli SE, Krebs HI, Stein J, Frontera WR, Hughes R, Hogan N (2004). Robotic therapy for chronic motor impairments after stroke: follow-up results. *Archives of Physical Medicine and Rehabilitation* 85: 1106–1111.
- Ferraro M, Palazzolo JJ, Krol J, Krebs HI, Hogan N, Volpe BT (2003). Robot-aided sensorimotor arm training improves outcome in patients with chronic stroke. *Neurology* 61: 1604–1607.
- Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Stegling S (1975). The post-stroke hemiplegic patient: a method for evaluation of physical performance. *Scandinavian Journal of Rehabilitation Medicine* 7: 13–31.
- Kilmer G, Roberts H, Hughes E, Li Y, Balluru B, Fan A, Giles W, Mokdad A, Jiles R (2008). Surveillance of certain health behaviors and conditions among states and selected local areas – Risk Factor Surveillance System (BRFSS) United States, 2006. *MMWR*, 57: 1–188.
- Krebs HI, Hogan N, Aisen ML, Volpe BT (1998). Robot aided neurorehabilitation. *IEEE Transactions on Rehabilitation Engineering* 6: 75–87.
- Krebs HI, Mernoff S, Fasoli SE, Hughes R, Stein J, Hogan N (2008). A comparison of functional and impairment-based robotic training in severe to moderate chronic stroke: a pilot study. *NeuroRehabilitation* 23: 81–87.

- Law M, Baptiste S, Carswell A, McColl MA, Polatajko H, Pollock N (1998). *The Canadian Occupational Performance Measure* (3rd ed). Ottawa, Ontario, Canada: Canadian Association of Occupational Therapists Publications, Ace.
- Lum PS, Burgar CG, Shor PC, Majmundar M, Van der Loos M (2002). Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke. *Archives of Physical Medicine and Rehabilitation* 83: 952–959.
- National Stroke Association (2008). What is stroke? (Available at: <http://www.stroke.org/site/PageServer?pagename=STROKE>) (Accessed 10 March 2008.)
- Radomski M, Trombly Latham C (2008a). Assessing abilities and capabilities: range of motion, strength and endurance. In: N Flinn, C Trombly, C Robinson Podolski (Eds.). *Occupational Therapy for Physical Dysfunction* (6th edn, pp. 91–185). Baltimore, MD: Lippincott Williams & Wilkins.
- Radomski M, Trombly Latham C (2008b). Optimizing motor behavior using Brunnstrom movement therapy approach. In: C Trombly Latham (Ed.). *Occupational Therapy for Physical Dysfunction* (6th edn, pp. 667–689). Baltimore, MD: Lippincott Williams & Wilkins.
- Taub E, Wolf SL (1997). Constraint induced movement techniques to facilitate upper extremity use in stroke patients. *Topics in Stroke Rehabilitation* 3: 38–61.
- Taub E, Miller NE, Novak TA, Cook EW 3rd, Fleming WC, Nepomuceno CS, Connell JS, Crago JE (1993). Technique to improve chronic motor deficit after stroke. *Archives of Physical Medicine and Rehabilitation* 74: 347–354.
- Taub E, Uswatte G, Pidikiti R (1999). Constraint-induced movement therapy: a new family of techniques with broad application to physical rehabilitation – a clinical review. *Journal of Rehabilitation Research and Development* 36: 1–17.
- Taub E, Uswatte G, Mark VW, Morris DM (2006). The learned nonuse phenomenon: implications for rehabilitation. *Europa Medicophysica* 42: 241–256.
- Uswatte G, Taub E (1999). Constraint-induced movement therapy: new approaches to outcome measurement in rehabilitation. In: DT Stuss, G Winocur, IH Robertson (Eds.). *Cognitive Rehabilitation* (pp. 215–229). Cambridge: Cambridge University Press.
- Volpe BT, Krebs HI, Hogan N, Edelsteinn L, Diels CM, Aisen ML (1999). Robot training enhanced motor outcome in patients with stroke maintained over 3 years. *Neurology* 53: 1874–1876.
- Volpe BT, Krebs HI, Hogan N (2003). Robot-aided sensorimotor training in stroke rehabilitation. *Advances in Neurology* 92: 429–433.
- Wolf SL, Catlin PA, Ellis M, Archer AL, Morgan B, Piacentino A (2001). Assessing Wolf motor function test as outcome measure for research in patients after stroke. *Stroke* 32: 1635–1639.

Address correspondence to Jennifer L. Smith, Sister Kenny Research Center, 800 East 28th Street, Minneapolis, MN 55407 (E-mail: [Jennifer.L.Smith@allina.com](mailto:Jennifer.L.Smith@allina.com)).