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Upper-limb function and recovery in the acute phase poststroke

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Abstract—This study evaluates stroke patients with upper-limb (UL) motor deficits using measures of impairment and "activity limitation" to quantify recovery of UL function poststroke and to identify predictors of UL function and predictors of UL recovery following stroke. The study also compares the recovery of UL function with that of the lower limb (LL). Measures of impairment and "activity limitation" of the UL and LL improved over the first 5 weeks. The Box and Block Test performance improved the most over 5 weeks (standardized response mean [SRM] = 1.34), followed closely by the 5-meter walk test (SRM = 0.97). Performances on measures of UL "activity limitation" measured at 1 week poststroke were the most important predictors of UL function 5 weeks poststroke. The results of this study do not support the belief that recovery of LL function is faster than that of UL.

Key words: acute phase, ADL, lower limb, outcome assessment, rehabilitation, stroke, upper limb.

INTRODUCTION

Cerebrovascular accident (CVA), or stroke, is a common disabling neurological disease affecting all ages, but primarily older adults. In many patients with severe stroke, the affected upper limb (UL) never becomes useful, even after therapy [1]. Only about 15 percent of those suffering from severe stroke recover hand function [2]. Limitations in the use of the UL have been shown to greatly contribute to diminished self-reported well-being 1 year following a stroke [3–4]. The outcome of patients with severe UL paresis is poor; in a study by Nakayama and associates, 83 percent of survivors had to be institutionalized [1].

Another study by Nakayama and associates looked at the recovery of UL function from the first week poststroke up until patients were discharged from acute care or died [5]. In this study, UL function was evaluated with the Barthel Index (BI) subscale for feeding and personal hygiene [6]. They found that only 18 percent of the patients with severe UL paresis achieved full UL function

Abbreviations: ADL = activity of daily living, ARAT = Action Research Arm Test, BBT = Box and Block Test, BI = Barthel Index, CI = confidence interval, CVA = cerebrovascular accident, FAT = Frenchay Arm Test, ICC = interclass correlation coefficient, LL = lower limb, 5MWT = 5-meter walk test, MLR = multiple linear regression, NHPT = Nine-Hole Peg Test, SD = standard deviation, SRM = standardized response mean, STREAM = Stroke Rehabilitation Assessment of Movement, TUG = Timed "Up and Go," UL = upper limb.

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and were not limited in their activities. The BI, however, is not sufficiently sensitive to detect deficits among persons with higher levels of functioning, because it has a ceiling effect when it is used to evaluate persons with a mild or moderate stroke [7]. Another limitation is that a perfect score on the BI can be achieved with the use of only the "unaffected" UL, giving no indication as to the actual level of recovery on the affected side.

A brief report by de Weerdt and associates [8] indicated that recovery of UL function assessed at 6 and 12 months poststroke with the use of the Action Research Arm Test (ARAT) [9], an activity limitation measure, was predicted by the initial score on the ARAT, exteroceptive sensation of light touch, and overall motor ability measured at 2 weeks poststroke. Most of the variability in the final score of the ARAT (44% and 33% for 6 and 12 months, respectively) was explained by the initial score on the ARAT. The other variables explained less than 4 percent of the variability at these times poststroke. The generalizability of these findings is limited because 37 percent of the original cohort was lost to follow-up.

Also, a general belief among rehabilitation professionals is that the lower limb (LL) recovers faster and more completely than the UL [10]. According to Kwakkel et al., most stroke survivors regain the ability to walk, whereas only between 30 and 66 percent of stroke survivors are able to use their affected arm [11]. In addition, an emerging hypothesis is that interdependence exists in the level between the UL and the LL. Dean and Shepherd demonstrated that the improvement in the ability to use the UL in a reaching task was linked to the improvement in the ability to use the affected leg for support and balance [12]. The ability to use the UL for support and balance will also affect recovery of walking and gait.

In their study, Duncan et al. compared the recovery of motor control of the UL with that of the LL and concluded that the recovery pattern over time was similar [10]. In this study, however, only a measure of impairment was used. Thus, it is not possible to determine whether subjects were restricted in the activities they performed using the affected limb. Recovery of the UL at the impairment level may not translate into purposeful use of the affected limb in a real-world setting.

When studying the recovery of the UL, one must distinguish between the recovery of basic motor control (impairments) and the recovery of use of the limb (activities). In their study, Kwakkel et al. found that significant differences in the level of recovery between the arm-training group and the control group were only detectable at 3 months, whereas differences between the leg-training group and the control group were detected as early as 6 weeks [13]. A lack of recovery reflected by performance on measures of activity limitation may cause therapists and patients to switch too quickly to the teaching of compensatory techniques using the "unaffected" UL and stop working on improving the motor function in the affected UL. This, in turn, may lead to "learned nonuse," in which repeated failed attempts to use the affected arm can lead to negative reinforcement in the use of that arm [14]. Poor outcomes in the rehabilitation of the UL have been noted to be due to the false sense of independence gained by the use of compensatory techniques [15]. That functional recovery should be viewed as a minimum use of compensatory strategies has been suggested [16].

The "unaffected" UL of stroke patients may also show motor deficits when compared with healthy subjects [17–20]. The resulting impact on the performance of the activities of daily living (ADLs) and the accomplishment of purposeful tasks can be devastating. Use of the UL is indispensable; it enables an individual to fulfill his/her roles in society and lead a gratifying life. According to the International Classification of Functioning, Disability and Health nomenclatures, functioning, which refers to all body functions, activities, and participation, can be affected following a stroke [21]. Our role as rehabilitation professionals is to prevent the development of activity limitations by providing appropriate therapy to reduce the impairments caused by a stroke [21].

Little is known about the pattern of UL recovery in the early period following stroke when the rate of recovery is expected to be the greatest and when most rehabilitation services are offered. At a time when healthcare workers are asked to justify their interventions and to measure the efficacy of their treatments, capturing the level at which the patient is situated in terms of recovery, identifying even small changes that occur in patients over the course of rehabilitation, and identifying the predictors of UL function during the acute phase poststroke are all important.

Therefore, the primary objective of the present study is to quantify the recovery of the UL at the level of impairments and "activity limitation" at 5 weeks poststroke. Secondary objectives are (1) to identify predictors of UL function at 5 weeks poststroke, (2) to identify predictors of UL recovery at 5 weeks poststroke where recovery is the difference between UL function at baseline and UL

function at 5 weeks poststroke, and (3) to compare estimates of recovery of UL function with estimates of recovery of LL function with the use of measures of impairment and measures of "activity limitation" of the UL and LL.

METHODS

Subjects

Subjects for this study were recruited from a consecutive series of patients admitted with a first stroke to five urban, university-based, acute care hospitals in Montreal, Canada. Persons with hemorrhagic and nonhemorrhagic strokes were included. Excluded from the study were persons presenting with complete recovery of the UL, major medical comorbidities that precluded participation in rehabilitation, or severe cognitive deficits, or those living more than 50 kilometers from Montreal. Because Canadians are covered by public health insurance whereby admission to hospital is based on stroke symptoms and not on the ability to pay, a representative sample of people was expected. The Institutional Review Board of McGill University, as well as the ethics committees of individual hospitals, approved this study.

Patients were screened for mental competency and self-perceived residual UL motor deficit. Cognitive status was evaluated with the abbreviated Mini-Mental State Examination [22]. A cutoff score of 14 out of a possible 22 was used because that cutoff has been suggested for identifying patients with significant cognitive impairment. In addition, patients were asked if they felt they had completely recovered their arm and hand function. Those who responded "yes" to the question were excluded. Any patients responding "no" were eligible to participate.

Procedures

Once eligible patients were identified, they were approached for participation. Consenting patients were assessed within the first week poststroke and again 4 weeks later. Information on age, comorbid conditions, and side and severity of the stroke was obtained at baseline from the medical chart. Subjects were assessed on a battery of UL and LL motor tests by an occupational therapist (JH) and a physical therapist (NS). Therapists were familiar with the outcome measures employed in this study and had undergone a training session in the use of the instruments. Standardized instructions were used routinely.

Measurement Instruments

Main Outcome Measure

The hand is required to perform fine movements to be functional. Manual dexterity is often used to estimate the level of performance of the UL in the accomplishment of activities of daily living (ADLs) [23] and it has been shown to be highly correlated with the level of independence in ADLs in older adults [24–25]. Therefore, the Box and Block Test (BBT) was chosen to evaluate unilateral manual dexterity [26]. The subject is required to move, one by one, the maximum number of blocks possible from one compartment of a box to another of equal size within 1 minute. Higher values indicate better gross manual dexterity. This test has been shown to have test-retest reliability greater than 0.9, and it correlated highly with another similar test of dexterity [26]. Desrosiers and associates verified the test-retest reliability and construct validity of this instrument in an elderly population with UL impairment [23]. Significant correlations were found between the BBT, an upper limb performance measure, and a measure of functional independence [23]. Because the BBT involves the grasping of objects, which is an activity in itself, it is considered here as an activity limitation measure.

Other Measures of UL Activity Limitation

The Frenchay Arm Test (FAT), a test of UL function, consists of five pass/fail tasks; the subject scores 1 for each task that is completed successfully [27]. Only the affected UL is evaluated. The validity of this test has been demonstrated [28]. Patients scoring 5 out of 5 are likely to use their affected UL, even if they feel it is not normal. Good interobserver and test-rest reliability of the FAT has also been reported [28].

The Nine-Hole Peg Test (NHPT) is a timed test of fine manual dexterity [29]. The subject takes nine dowels from the table top, puts them into nine holes on a board, and then takes the dowels out again [30]. A lower score indicates better fine manual dexterity. High simultaneous interrater reliability and moderate test-retest reliability have been demonstrated. Also, clinical norms for adults 20 to 75+ years of age for both males and females have been established [31]. The NHPT was administered at baseline only for purposes of predicting UL function at 5 weeks.

Measures of UL Impairment

The Jamar™ dynamometer (Jamar Technologies, Horsham, PA) was used to measure grip strength. Three grip strength measures of each hand were taken and the highest score was retained. A study by Mathiowetz et al. indicated that good interrater and test-retest reliability can be achieved by the use of standardized positioning and instructions [32]. Gender and age-specific normative data are available [33–34].

The Stroke Rehabilitation Assessment of Movement (STREAM) consists of 30 items and is divided into three sections: voluntary movement of the UL, voluntary movement of the LL, and basic mobility [35]. It is scored by an evaluator viewing subject's performance. The total and the subtotals are scored out of 100, with higher values indicating higher levels of voluntary movement or mobility. Content validity and excellent interrater and intrarater reliability have been reported [36]. Scores on the STREAM have also been shown to be associated with scores on other commonly used measures such as the BBT, the BI, gait speed, and the Timed "Up and Go" (TUG) [37]. For purposes of quantifying UL recovery, only the UL subscale was used.

Measures of LL Activity Limitation

Gait speed and functional mobility measures were used to compare the recovery of UL function to the recovery of LL function. Gait speed is a valid and reliable measure of stroke outcome and has been shown to correlate with the level of independence in daily living [38], as well as functional mobility [39]. In this study, walking speed at a comfortable pace was determined over a distance of 5 meters, known as the 5-meter walk test (5MWT). The 5MWT has been found more responsive than the 5-meter test (maximum speed), the 10-meter test (comfortable speed), and the 10-meter test (maximum speed) [40]. In addition to being used to compare recovery of UL and LL function, this test was used as a predictor of UL function and UL recovery. Indeed, patients' levels of UL function may depend on their levels of LL function. In order to be able to use their ULs in their daily activities, patients need a stable trunk, as well as balance in sitting and standing.

An assessment of functional mobility, the TUG measures, in seconds, the time taken by an individual to stand up from a standard arm chair, walk a distance of 3 meters, turn, walk back to the chair, and sit down [39]. A shorter time indicates better functional mobility. Excellent intrarater and interrater reliability has been demonstrated in elderly subjects [39], and it has been shown to correlate with the Berg Balance scale, the BI, and gait speed [3]. The TUG has demonstrated excellent test-retest reliability (interclass correlation coefficient [ICC] = 0.99) and interrater reliability (ICC = 0.99) in elderly subjects [39].

Data Analysis

We compared clinical characteristics of the study participants to those of the eligible nonparticipants using chi-square tests for categorical variables (gender, side of the lesion, type of CVA, and severity of CVA) and a *t*-test for the continuous variable, age. We analyzed the data using the Statistical Analysis System (version 6.11, 1995, SAS, Cary, NC).

Recovery of UL Function

We estimated recovery of UL function between 1 and 5 weeks poststroke by the change scores on the BBT, the FAT, and grip strength, as well as the UL subscale of the STREAM. Paired *t*-tests were performed to evaluate if changes were significant. Estimates of the difference between the initial and the 5-week evaluations are presented later in the Results section, along with 95 percent confidence intervals (CIs). If the 95 percent CI excludes 0, it is likely that a true change occurred in the population.

Predictors of UL Function

Multiple linear regression (MLR) analyses were used to identify baseline variables that predicted UL function at 5 weeks poststroke. We estimated the primary measure of UL function using the final score on the BBT at 5 weeks poststroke (dependent variable). Potential predictors (independent variables) of UL function included fine manual dexterity (NHPT), UL function (FAT), grip strength, motor recovery (STREAM), gait speed (5MWT), functional mobility (TUG), level of cognition, and perceptual neglect 1 week poststroke. The predictive ability of sociodemographic and stroke-related variables such as age, gender, hand dominance, number of comorbid conditions, type of stroke, and side of lesion was also evaluated.

When the final BBT score was the outcome, two models were developed, one with and one without the initial BBT score as an independent variable. Also, because the number of independent variables was quite large with respect to the number of subjects, separate models were created for three groups of variables. The first group comprised the six sociodemographic and

stroke-related variables just mentioned. The second and third groups, which included measures of impairment and activity limitation for the UL and for the LL, respectively, were modeled separately. Because few subjects had cognitive problems or perceptual neglect, these two variables were dropped from the analyses. Hand dominance was also dropped from the analyses because only a few subjects were left-handed ($n = 4$). Also, because the 5MWT and the TUG are closely related ($r = -0.81$) and measure approximately the same construct, only the 5MWT was used. Because the number of rehabilitation sessions is a proxy to stroke severity, it was not used as a variable in the MLR analysis. Only the significant predictors from each group were retained. The significant variables were then used together in the same equation to obtain the final model.

The modeling strategy was all possible subsets regression, which evaluates the prediction of each variable with all other variables in the model. To determine the best fitting model, we considered dependent variables both continuous and categorical. The STREAM, the FAT, and grip strength were eventually included only as dichotomous variables split approximately at the median. We calculated standardized regression parameters for all continuous variables to compare relative strengths of predictors measured on different scales. Standardized regression coefficients are equal to the parameter estimate (ß) multiplied by the standard deviation (SD) of the measure and are interpreted as the change in outcome associated with one SD change in the initial measure. Residual and partial regression plots were generated and the assumptions of normality, homoscedasticity, and linearity were verified. To test the fit of models, we used Mallow's Cp. When fit is satisfactory, Mallow's Cp will be approximately equal to the number of parameters estimated in the model (number of variables plus intercept). The assumptions for all of the models were verified and found to hold; fit statistics were satisfactory. To test whether the small sample size influenced the regression parameters, we randomly split the study sample in two and repeated the models.

Predictors of UL Recovery

We tested another MLR model with the change between initial and final BBT score as the outcome to determine the predictors of UL recovery while adjusting for the effects of other variables. This model did not include the initial BBT score, as recommended by Suissa [41].

Comparison Between Recovery of UL Function and Recovery of LL Function

We compared the recovery of UL function to the recovery of LL function using the standardized response mean (SRM) for each measure. The SRM is the mean change in score divided by the SD of change in scores [42]. The SRM accounts for errors at both times. It is a unitless measure of change that allows the comparison of scores on different instruments. It is a variant of the effect size, and higher values indicate a better responsiveness. Variants of effect sizes came from Cohen [42]: 0.2 or less is small, 0.5 is moderate, and 0.8 or more is large. CIs for the SRMs were subsequently derived with the procedure described by Liang [43].

Because of the concern that UL function has a higher ceiling than LL function, we compared each person's score on the BBT and the 5MWT to age- and gender-specific norms and calculated percent-predicted values [23,44]. From these new variables, we again derived SRM and CI. We used the BBT and 5MWT, two measures of activity limitation, because manual dexterity and gait speed are important indicators of dependence in ADLs [24–25,38], for which norms have been published [45].

Missing Values

At the initial evaluation, 17 persons (31%) were unable to walk and hence could not be assigned values for the 5MWT or for the TUG. For the 5MWT, 0 m/s was a reasonable substitute. For the TUG, a comparable group was not available from which values for missing data could be imputed, so values equal to twice the highest TUG score obtained in the sample were substituted. This choice was arbitrary, but it was necessary to choose a value higher than for those who could complete the test but not so extreme so as to affect the mean values.

RESULTS

Description of Study Population

Out of a total of 357 patients who were identified as having had a first-time stroke during the period of recruitment, 170 people met the eligibility criteria of the study and 65 were approached. The 56 subjects who agreed to participate signed an informed consent and completed the baseline evaluation. Of the 170 patients who met the eligibility criteria, 105 individuals were unavailable to the investigators during the 10-day period

of recruitment following their stroke. One patient died before the second evaluation and nine refused to participate in the study. The final study sample, therefore, comprised 55 patients; 50 of these also participated in the study by Salbach et al. on the recovery of gait speed [40].

Table 1 presents the clinical characteristics of study participants. The age of the participants ranged from 25 to 95 years, with an average of 66 years; 64 percent of the participants were males. There were no statistically significant differences between study participants and the nonparticipants for age, gender, side, or type of stroke. A difference was found, however, in the severity of the stroke. The study sample comprised more moderate and severe strokes than did the nonparticipants.

Recovery of UL Function

Table 2 presents means and SDs on UL measures at the first and second evaluations. The differences in scores between the first and the second evaluation are also given. Significant improvements in performance on the main outcome measure, the BBT, were observed for both the affected and unaffected hands. Scores on the FAT also increased significantly by 1 point out of a possible 5 points. On the BBT, mean scores on the first evaluation increased from 34 percent to 51 percent of the mean age- and gender-specific values for the affected side. An increase of 17 percent of the mean age- and gender-specific normal value is thus noted on the affected side.

Table 1.
Demographic and clinical characteristics of study participants (n = 55).

Characteristic	Value
Mean Age ± Standard Deviation	66 ± 15
Gender No. (%)* Men/Women	35 (64)/20 (36)
Side of Lesion No. (%) Right/Left/Bilateral	26 (47)/28 (51)/1 (2)
Type of CVA No. (%) Ischemic/Hemorrhagic	51 (93)/4 (7)
Severity of CVA† Mild/Moderate/Severe	9 (16)/28 (51)/18 (33)

*Percentages may not total 100 because of rounding.
†Stroke severity based on Canadian Neurological Scale (CNS) scores: mild CNS 11, moderate CNS 9–11, severe CNS <9. Otherwise, severity established from medical charts.
CVA = cerebrovascular accident

For both men and women, a significant improvement in grip strength was noted on the affected side. Significant gains on the UL subscale of the STREAM were also observed.

Predictors of UL Function

The predictors of UL function are presented in **Table 3**, with or without including the initial BBT score. The independent variables that significantly explained the final score on the BBT (model 1) included the initial score on the BBT (affected side), the total STREAM, the FAT, the 5MWT, and the NHPT. This first model explained 92 percent of the variance of the final score on the BBT.

When the same model was then constructed without the initial score on the BBT (model 2) as a predictor variable, only the FAT, the 5MWT, and grip strength on the affected side were significant predictors. This second model explained 84 percent of the variance.

Results of the MLR analysis showing variables that predict UL function for all models as well as the standard parameter estimates (indicated by an asterisk) are presented in **Table 4**. For the initial score on the BBT, the standard parameter estimate of the initial score on the BBT is 15.7, meaning that 1 SD on the BBT at initial evaluation is associated with an increase of 15.7 blocks on the final BBT.

Predictors of UL Recovery

In the third MLR model, UL recovery, the STREAM, the FAT, and the NHPT were significant predictors of the difference in the mean score on the BBT between the first and the second evaluations. The model explained 42 percent of the variance of the mean change on the BBT (right column in **Table 4**).

As presented in **Table 4**, for the change score on the BBT between the first and the second evaluation on the BBT, a person scoring over 80 out of 100 on the STREAM would be estimated to change by 12 blocks more than a person with a poor outcome on the STREAM (<80).

Comparison Between Recovery of UL Function and Recovery of LL Function

Table 5 presents the SRMs for UL and LL outcome measures reflecting similar constructs. At the level of impairment, as measured by the STREAM, the SRM for the UL subscale was not significantly different from the SRM of the LL subscale, as shown by the overlapping CIs.

Table 2.
Recovery of upper-limb function at 5 weeks poststroke (n = 55).

Level of Measurement	Initial Evaluation	2nd Evaluation (5 weeks)	Difference Between 1st and 2nd Evaluations	95% Confidence Interval
Measures of Activity Limitation (scale)				
Box and Block Test (No. of blocks)				
Affected Side	24 ± 21	36 ± 23	12 ± 9	9.4 – 14.3
Unaffected Side	49 ± 14	52 ± 12	7 ± 8	5.2 – 9.7
Frenchay Arm Test (/5)	3 ± 2	4 ± 2	1 ± 1	0.3 – 1.0
Measures of Impairment Grip Strength (kg)				
Affected Side: Males	19.2 ± 15.0	24.4 ± 15.2	5.1 ± 5.6	3.4 – 7.1
Affected Side: Females	12.9 ± 10.7	15.5 ± 12.4	2.6 ± 4.4	0.6 – 4.6
Unaffected Side: Males	35.9 ± 9.5	36.4 ± 9.9	0.6 ± 4.0	–0.9 – 2.0
Unaffected Side: Females	21.4 ± 8.2	21.9 ± 7.8	0.5 ± 3.1	–0.7 – 2.1
STREAM Upper Limb (/100)	70 ± 24	83 ± 34	13 ± 17	8.2 – 17.4

STREAM = Stroke Rehabilitation Assessment of Movement
Note: Values are given in mean ± standard deviation.

Table 3.
Percentage of variability (R^2) of Box and Block Test explained by significant predictors (n = 55).

Initial Measure	BBT_{5w} vs. Initial Measures (%)		ΔBBT vs. Initial Measures (%)
	BBT	No BBT	
BBT (affected side)	91.2	—	—
STREAM	4.7	—	52.8
Frenchay Arm Test	2.2	89.9	30.5
5-Meter Walk Test	1.1	4.7	—
Nine-Hole Peg Test (affected side)	0.8	—	16.7
Grip Strength (affected side)	—	5.4	—
R^2	92.0	84.0	42.0

BBT = Box and Block Test
BBT_{5w} = BBT at 5 weeks poststroke
ΔBBT = mean difference between first (~1 week) and second evaluation (5 weeks) on BBT
STREAM = Stroke Rehabilitation Assessment of Movement

Grip strength on the affected side was also not significantly different from the LL subscale of the STREAM.

The SRMs for measures used to compare activity limitation for the UL and LL were significantly different when we compared the BBT to the 5MWT. Indeed, the SRM for the BBT was greater than the SRM for the 5MWT, with minimal overlap of the CI (t-value = 2.38, degrees of freedom: 54). The SRMs for the FAT and the TUG were lower than for the previous measures, but they were not significantly different from one another.

We also calculated the SRM for the BBT and the 5MWT using age- and gender-specific norms and percent predicted values [23,44]. For example, the percent-predicted values for the BBT on the affected side were 34 percent (SD = 28.8) and 51 percent (SD = 31.7) for the first and second evaluations, respectively. For the 5MWT, these values were 44 percent and 66 percent. The estimated SRMs and their CI for percent predicted values did not differ from those using raw values.

DISCUSSION

The main objectives of this study were to (1) quantify the recovery of the UL at the level of impairment and "activity limitation" at 5 weeks poststroke, (2) identify predictors of UL function and predictors of UL recovery at 5 weeks poststroke, and (3) compare estimates of recovery of UL function with estimates of recovery of LL function using measures of impairment and measures of "activity limitation" of the ULs and LLs.

Table 4.
Results of multiple linear regression showing variables that significantly explain upper-limb function or recovery 5 weeks poststroke (n = 55).

Significant Predictor (Measurement Scale)	Standardized β^*	Standard Error	R^2
BBT_{5w} vs. Initial Measures			
BBT (per 1 SD/21 blocks)	15.7	2.1	0.92
STREAM† ≤80 vs. >80	–10.9	3.2	—
Frenchay Arm Test† ≤3 vs. ≥4	–13.1	3.8	—
Nine-Hole Peg Test (per 60 s)	–1.2	0.6	—
5-Meter Walk Test (per 1 SD/0.37 m/s)	2.7	1.2	—
BBT_{5w} vs. Initial Measures (excluding BBT)			
Frenchay Arm Test† ≤3 vs. ≥4	–21.1	5.6	0.84
5-Meter Walk Test (per 1 SD/0.37 m/s)	5.7	1.7	—
Grip Strength† (≤0–20 kg vs. >20 kg)	–12.8	5.2	—
ΔBBT vs. Initial Measures			
STREAM† ≤80 vs. >80	–12.4	3.3	0.42
Frenchay Arm Test† ≤3 vs. ≥4	–11.5	3.5	—
Nine-Hole Peg Test (per 60 s)	–2.1	0.6	—

Note: Negative regression coefficients arise when persons with lower function are compared to persons with higher function.
Mallow's Cp was 6, 4, and 4 for models 1, 2, and 3, respectively, equivalent to number of parameters estimated indicating satisfactory fit.
*Parameter estimate (β) standardized to the units or categories units indicate; β standard error (SE) is equivalent to a t-test.
†Continuous variables included as categorical variables.
BBT = Box and Block Test
BBT_{5w} = BBT at 5 weeks poststroke
ΔBBT = mean difference between first (~1 week) and second evaluation (5 weeks) on BBT
STREAM = Stroke Rehabilitation Assessment of Movement
SD = standard deviation

Table 5.
Standardized response means (SRMs) for outcome measures (n = 55).

Level of Measurement	Outcome Measure	SRM	95% Confidence Interval
Activity Limitation	BBT (affected side)	1.34*	1.02 – 1.63
	5-Meter Walk Test	0.97*	0.74 – 1.18
	BBT (unaffected side)	0.90	0.58 – 1.20
	Frenchay Arm Test	0.60	0.42 – 0.76
	Timed "Up and Go"	0.57	0.43 – 0.72
Impairment	STREAM Total	0.98	0.74 – 1.17
	STREAM (upper limb)	0.75	0.56 – 0.93
	STREAM (lower limb)	0.63	0.36 – 0.86
	Grip Strength (affected side)	0.82	0.60 – 1.04
	Grip Strength (unaffected side)	0.17	–0.11 – 0.44

*SRMs and 95% confidence intervals calculated from percent-predicted age- and gender-specific values.
BBT = Box and Block Test
STREAM = Stroke Rehabilitation Assessment of Movement

Recovery of UL Function

UL function as measured with the BBT and the FAT increased significantly over the first 5 weeks following stroke. According to McEwen [3], the BBT is a significant predictor of physical health as measured by the Medical Outcomes Study 36-Item Short Form Questionnaire [46]. She found that an additional seven blocks increased, by an average of 2, the Physical Component

Summary Score, and this amount is considered clinically relevant [46]. This finding implies that the improvement occurring during the first 5 weeks poststroke in the affected arm is clinically meaningful and may actually translate into greater use of the affected limb in "real-world situations."

An important finding is that, on the BBT, both the affected and the unaffected ULs had scores lower than age- and gender-specific normal values at initial assessment. These results concur with those of Desrosiers and associates, who compared function of the "unaffected" UL to function of the UL on the same side in healthy subjects [23].

UL impairments as measured by grip strength on the affected side and the STREAM also improved significantly over the first 5 weeks. Contrary to the BBT, grip strength was within normal limits on the "unaffected" side and did not improve significantly over the 5-week period. Concentrating on the integration of meaningful activities involving both the unaffected and the affected UL may enhance overall levels of function. Indeed, according to van der Lee, therapy aimed at improving UL function should focus on the performance of ADLs [47]. It is also in accordance with evidence several studies that have demonstrated that bimanual training may benefit motor learning because the arms act as a unit in the brain [48–50].

Predictors of UL Function

UL function estimated using the BBT at 1 month poststroke is mainly predicted by the performance on the BBT measured at baseline. Other predictors, in order of decreasing importance, include voluntary motor ability of the UL and LL and basic mobility (total STREAM), global arm function (FAT), gait speed (5MWT), and fine manual dexterity (NHPT).

Including the initial score as a covariate in a regression model, however, could lead to biased estimates because an assumption of linear regression, the independence of the error term from the outcome variable, is violated [51]. This limits our ability to test the value of the BBT as a predictor of UL function. For this reason, we ran a second model that did not include the BBT as a predictor variable. When the initial score on the BBT was not considered in the model, the FAT, another activity limitation measure, explained most of the variability. This indicates that if clinicians want to predict UL function at the level of activity limitation, they should use another measure of activity limitation.

Predictors of UL Recovery

The most important predictor of the change in score on the BBT between the first and the second evaluation was voluntary movement of the UL and LL, as well as basic mobility represented by the total STREAM score. The significance of global voluntary movements and basic mobility as predictors of the change in UL function may indicate that the recovery processes of the UL and LL are not totally independent. This is easy to understand in relation to the performance of many everyday activities. In order to have functional and coordinated movements of the UL, a person needs a stable trunk, as well as balance in sitting and standing, which implies a functional LL. This significance also indicates that having voluntary movement initially contributes to functional recovery. Indeed, neurophysiological research has shown that repetitive motor activity, even very simple movements, forms the basis of motor learning and recovery by inducing changes in the cortex [52]. Based on this growing body of evidence, studies using new therapeutic approaches such as Constraint-Induced Movement Therapy and the forced-use approach have yielded good results in terms of UL recovery. These studies require patients to have a certain amount of movement initially in their affected UL.

The change score or improvement in UL function is also predicted by voluntary movements and function of both limbs. The results of the current study are in accordance with a study by Dean and Shepherd, who demonstrated that the improvement in the ability to use the ULs in a reaching task was linked to the improvement in the ability to use the affected leg for support and balance [12]. And, in a more recent study, Hsieh et al. also found that trunk control was a significant and strong predictor of ADL function as measured by the BI and the Frenchay Activities Index [53]. Both of these indexes comprise items requiring the use of the ULs.

Thus, to make a realistic prognosis of recovery of function, one must initially assess the severity of the UL deficits using measures that are well matched to the level of recovery of the patient. The use of adequate measures of impairment and motor control of both the UL and the LL, which are the building blocks of more integrated functional activities, is essential. Again, these findings also suggests the benefits of generalized training that includes both UL and LL training integrated into the performance of meaningful activities such as ADLs and instrumental ADLs.

Comparison Between Recovery of UL Function and Recovery of LL Function

We compared the extent of recovery in the UL and LL at the level of impairment and activity limitation using SRMs. At the level of activity limitation, as measured by the BBT and the 5MWT, the UL recovered to a greater extent than the LL. The SRM values for these measures are considered large according to Cohen [42]. Also, at the level of activity limitation, as measured with the FAT and the TUG, no significant difference occurred between recovery of the UL and recovery of the LL. Moreover, the extent of recovery was less on these two measures, possibly because they involve more integrated tasks such as combing hair and getting up from a chair. At the level of impairment, as measured by the STREAM and grip strength of the affected side, the UL recovers at least as well as the LL (**Table 5**).

To account for potential differences in the ceilings of the measures, we also calculated the SRMs for the BBT and the 5MWT using percent-predicted values. Results obtained with this procedure were identical for both tests, possibly because these two tests have less of a ceiling to their measurement than scales with constrained maximum values. Although UL function seemed to improve the most, power is insufficient to detect important differences between the UL and the LL on measure of UL and LL function. In addition, the greater SRM for the UL may not reflect necessarily greater functional change. The 5MWT is both a test and a function, while the BBT is only a test and has no functional component. Thus, higher scores on the BBT may not translate to function as well as the 5MWT. According to these results, there is no direct evidence that the recovery of the UL is vastly different from that of the LL over the first 5 weeks poststroke. This is contrary to popular belief that recovery of the UL is slower and less complete than that of the LL. These results, however, are in accordance with those of Duncan et al., who concluded that the recovery patterns of the UL and LL over time were similar at the impairment level [10]. This is an important finding for all rehabilitation professionals.

Limitations of Study

It is important to point out the limitations of this study. First, the results of the analyses were based on performance by a defined group of stroke patients. This group differed significantly from the nonparticipants in terms of severity of stroke. The sample population therefore may not represent the target population, so the results are only applicable to patients with the characteristics of the present study sample.

Second, because patients were only followed for 5 weeks, the prediction of recovery is limited to this time period. Time to detect improvements in UL function may not have been sufficient. Also, patients were recruited an average of 8 days poststroke, so some may have experienced recovery prior to their first evaluation. This would have led to an underestimation of the change between the first and second evaluations of the outcome measures.

Third, a measure of activity limitation of the UL involving functional tasks of the UL only would have been necessary for the adequate assessment of the recovery at this level.

Finally, we calculated the sample size for this study to detect a simple correlation ≥ 0.5 at 90 percent power, and a two-tailed alpha level of significance of 0.05. To detect lower correlations between the dependent and independent variables, or to capture smaller differences in mean score between the first and second evaluations, we would have needed a larger sample size.

CONCLUSION

We observed a significant improvement in UL function in the first 5 weeks poststroke at the level of impairment and at the level of activity limitation. The results of this study suggest that the extent of UL deficits assessed in the first week following a stroke with the use of a measure of activity limitation is a good prognostic indicator of UL function at 5 weeks poststroke and should be used for the planning of treatment strategies. In addition, measures of activity limitation, which are more useful to the evaluation of treatment efficacy, will better indicate whether the level of recovery translated into functional use of the limb.

Voluntary movements (STREAM) of both UL and LL predict UL recovery poststroke. The use of scales at the level of impairment may help capture components that are the building blocks of the active use of the UL in purposeful activities, especially in patients whose UL is initially severely affected. This, in turn, will assist in the planning of an appropriate treatment or intervention aimed at minimizing activity limitations by targeting the underlying impairments. The results of this study do not support the general belief that motor recovery of UL

function is different from that of the LL. However, there is some support for a greater recovery of the UL at the level of activity limitations.

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