Longitudinal Analysis of the Recovery of Trunk Control and Upper Extremity following Stroke: An Individual Growth Curve Approach

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ABSTRACT

Background and Purpose

Trunk control is thought to contribute to upper extremity function. It is unclear whether recovery of trunk control has an impact on the recovery of upper extremity in people with stroke. This longitudinal study monitored the recovery of trunk control and upper extremity in the first 6 months following stroke.

Methods

Forty-five participants with stroke were assessed monthly for 6 months following stroke. Trunk control was assessed using the Trunk Impairment Scale (TIS); upper extremity impairment and function were assessed with the Fugl-Meyer (FMA) and Streamlined Wolf Motor Function Test (SWMFT) respectively. The SWMFT included the performance time (SWMFT-Time) and functional ability scale (SWMFT-FAS). The individual growth curve modeling was used to analyze the longitudinal data.

Results

The recovery curve of TIS, FMA, SWMFT-Time and SWMFT-FAS followed a quadratic trend, with the rate of recovery decreasing from the first to sixth month. As TIS score improved over time, FMA, SWMFT-Time and SWMFT-FAS improved in parallel with the TIS score. TIS at each time point was found to be a significant predictor of FMA, SWMFT-Time and SWMFT-FAS at 6 months post stroke.

Conclusion

Our work has provided, for the first time, substantial evidence that the pattern of recovery of trunk control is similar to that of the recovery of upper extremity following stroke. In addition, this study provides evidence on which to design a prospective study to evaluate whether improvement in trunk control early post stroke results in better long-term upper extremity function.

INTRODUCTION

Stroke affects control of the trunk muscles and therefore the ability to remain upright, adjust to perturbations and perform selective trunk movements to maintain stability[1,2]. The trunk is thought to play an integral role in postural stabilization supporting controlled movement of the extremities during task performance [2,3]. The development of trunk stability and control is considered to be a prerequisite to upper extremity function and use of the hand [4] and has been validated in a clinical trial. In a previous study by our group [5], we found that external trunk support improved trunk control in people with chronic stroke; and had a statistically significant effect on upper extremity function in chronic stroke participants and healthy controls. The findings suggest an association between trunk control and upper extremity. Provision of lower trunk and lumbar stabilization from an external support enables an improved ability to use the upper extremity for functional activities.

Having demonstrated the association between trunk control and upper extremity in a cross-sectional study [5], we examined the relationship between trunk control and upper extremity function through a longitudinal study, to address the question of whether recovery of trunk control and recovery of upper extremity function during the first 6 months following stroke are related.

METHODS

A longitudinal repeated measures design was used in which trunk control and upper extremity impairment and function were measured on 6 occasions over 6 months.

Sample size calculation

Sample size estimation allowed for attrition, as reported by Hedeker et al [6], was as follows: considering the correlation among the repeated measures to be $\rho=0.5$, an attrition rate of 0.05 and medium effect size, a between-group difference of 0.5 standard deviation at each time point (as described by Cohen [7]), 42 participants were required to achieve a 80% power in a 2-sided 5% test [6]. To allow for further 5% dropout in view of the long period of follow-up of 6 months, 45 consecutive sub-acute stroke participants were recruited.

Participants

Participants with stroke, as confirmed by CT scan, were recruited while they were inpatients at a tertiary rehabilitation centre. Inclusion criteria were: i) aged 21 years or over; ii) less than 6 months post stroke; iii) able to understand the purpose of the study and follow simple instructions; and iv) able to sit unsupported for ten seconds. Exclusion criteria were i) people with brainstem or cerebellar stroke and ii) presence of neurological or orthopedic pathology or acute low back pain.

The Institutional Review Board of the National Healthcare Group of Singapore (Ethics number 2014/00229) approved the study. All participants provided written informed consent. This study conforms to the STROBE guidelines.

Outcome measures

The Trunk Impairment Scale (TIS) was used to evaluate trunk control in the participants [1]. The TIS comprises three subscales that assess static sitting balance, dynamic sitting balance, and trunk coordination generating a total score between 0 and 23, where a higher score indicates better trunk control. Static sitting balance (score range 0 to 7) evaluates the ability to remain in seated position with both feet on the floor and with the legs crossed [8]. The dynamic sitting balance sub-scale (score range 0 to10) assesses lateral flexion of the trunk, initiated from the upper and lower part of the trunk [8]. Trunk coordination subscale (score range 0 to 6) assesses rotation from the shoulder and pelvic girdle in the horizontal plane [8].

Motor impairment was measured with the upper extremity (UE) subsection of the Fugl-Meyer Assessment (FMA) [9]. Each of the 33 items of UE FMA is rated on a 3-point scale. The maximum score is therefore 66 points. Upper extremity function was measured with the Streamlined Wolf Motor Function Test (SWMFT) [10]. The six SWMFT tasks appropriate for people with subacute stroke were lifting hand from the lap to the table, lifting hand from table to a box, lifting a can to mouth, lifting a pencil with 3-jaw chuck grasp, folding towel, reach and retrieve a one-pound weight [11]. The performance time (SWMFT-Time) of the tasks was measured with a stopwatch and a 6-point Functional Ability Scale (SWMFT-FAS) was used to rate the quality of movement during performance of the tasks [11]. The TIS, FMA and SWMFT have demonstrated good psychometric properties and good clinical utility that are appropriate for people with sub-acute stroke [12].

Procedures

The TIS, FMA and S-WMFT were applied monthly for 6 months. The first assessment session was conducted at the tertiary rehabilitation centre. For subsequent follow-up assessments, participants were offered a choice of the rehabilitation centre or in their own home. This strategy aimed to reduce dropout. The principal investigator (SKW) conducted all assessments, using the same set of testing equipment (wooden stools, height-adjustable table, SWMFT equipment and assessment chart template) were used throughout the study in both the rehabilitation centre and the participant's home thus standardising the administration of measures.

During the assessment session, the participant sat unsupported on a stool with their thighs fully supported, knees at 90 degrees and feet flat on the ground. Order of assessments was the same for each participant at each time point and was: FMA; TIS; SWMFT.

Statistical analysis

Data analysis was performed using the IBM SPSS Statistics 22 software. The level of statistical significance was set at $p < 0.05$ for all tests. The longitudinal data analysis was conducted using the individual growth curve (IGC) modeling, which was performed with the "*Linear Mixed Model"* function in SPSS. The IGC modeling technique examines the intra-individual systematic change and inter-individual differences in outcomes over time [13-18]. It generates unique trajectories of individuals, in addition to group analysis, in repeated measures data [19]. Therefore, IGC modeling is more robust than the traditional statistical analysis techniques (for example, repeated measures analysis of variance, ANOVA) in the analysis of longitudinal data [16,20,21]. In addition, IGC modeling is able to accommodate outcome data missing at random without excluding individuals with incomplete data for analysis [16,22,23].

Individual models for the TIS, FMA, SWMFT-Time and SWMFT-FAS were constructed using a 4-stage process. Estimation of parameter values for all models were performed by the maximum likelihood method [21]. First, we determined the form of trajectory (linear, quadratic or cubic) that best fit the data by using the deviance statistic (-2 log likelihood ratio test [-2LL]) to compare the models [24]. The difference in the deviance statistics between the models is approximately chi-square distributed with degrees of freedom equal to the difference in the number of estimated parameters between the models [13,21]. If the resulting value of the deviance statistics is significant, then the model with the lower deviance value fits the data significantly better [21]. Second, we used the heterogeneous first-order autoregressive covariance structure for subsequent analysis, with the sound assumption that the correlations between repeated measurements get smaller over time [20]. Third, the model would be fitted with one predictor at a time to evaluate its contribution in explaining the intra-individual and inter-individual differences in trajectories and outcome variables. The interaction term (predictor × time) was included to examine whether the proposed predictor variable predicted change in outcome variable over time. After testing each predictor individually, the significant predictors were included in the final model in order to determine which predictors accounted for unique variance in the outcome variable. Finally, we removed those predictors that were non-significant in the presence of other predictors to determine the most parsimonious multivariable model based on the model with the largest reduction in the proportional variance as compared to the linear/quadratic/cubic model with no predictors.

RESULTS

Participants

Forty-five stroke participants were recruited (Figure 1). The clinical and demographic characteristics of participants are summarised in Table 1. At recruitment, 86.7% of the stroke participants had moderate to severe (based on the FMA scores [9]) impairment of the upper extremity and 95.6% of the participants had poor to fair trunk control.

Dropout and missing data

Over the entire data collection period, four participants dropped out at different time points due to various reasons (Figure 1). All the missing data were classified as “missing completely at random” (MCAR) because the reasons for dropout were totally unrelated to the measured variables and outcomes. Little & Rubin [25] classified data as MCAR when the probability of missing data on a variable *X* is unrelated to other measured variables and to the values of *X* itself. Due to the dropout, the total number of measurement data was 255 instead of 270. Despite some missing data in this study, the IGC modeling technique is robust enough to handle missing data at random [16,22,23].

Individual growth curve models for TIS, FMA, SWMFT-Time and SWMFT-FAS

Through the systematic model building, it was demonstrated that the recovery curves of TIS, FMA, SWMFT-Time and SWMFT-FAS fit the quadratic trend.

Figure 2 detailed the prototypical plots of all the recovery curves based on the IGC modeling. The rate of recovery decreased from the first to sixth month.

For the TIS and FMA, the IGC modeling demonstrated a negative and significant intercept-slope covariance. This suggests that as the intercept increased, the slope decreased (Figure 3). In other words, those participants with lower initial score demonstrated a faster rate of change, on average, than those with higher initial score; and vice versa.

For the SWMFT-Time, results demonstrated a negative and significant intercept-slope covariance. Note that the rate of change for SWMFT-Time was negative. Hence, this suggests that as the intercept increased, the slope increased (in negative direction) (Figure 4). In other words, those participants with higher initial SWMFT-Time demonstrated a faster rate of change (in negative direction), on average, than those with lower initial SWMFT-Time.

For the SWMFT-FAS, results demonstrated a negative and non-significant intercept-slope covariance (Figure 4). Hence, this suggests that there was lack of systematic relationship between initial SWMFT-FAS score and trajectory of the recovery curve of SWMFT-FAS.

Instantaneous rate of change of the recovery curves of TIS and FMA at each time point

The rate of change of TIS recovery was similar to the rate of change of FMA recovery (Figure 5). As TIS scores improved over time, FMA improved almost in parallel with the TIS increase (Figure 5). Using the data on the instantaneous rate of change at each time point, the plots of the rate of change over time showed similar linear decrease, with slope gradient of -0.61 and -0.68 for TIS and FMA respectively (Figure 6).

Predictors of trunk control and upper extremity impairment and function

The statistically significant predictors of TIS were stroke type, time post stroke, initial severity of UE impairment and initial trunk impairment ($p < 0.001$) (Appendix I). The TIS was found to be a significant predictor of FMA ($p < 0.001$), SWMFT-Time ($p < 0.001$) and SWMFT-FAS ($p < 0.01$) (Appendices II, III and IV). This implies that TIS is a predictor that has an influence on the overall shape of the recovery curves.

DISCUSSION

The IGC modelling demonstrated that the recovery curves of trunk control (TIS), upper extremity impairment (FMA) and upper extremity function (SWMFT-Time and SWMFT-FAS) in the first 6 months post stroke followed a quadratic trend. The rate of recovery of TIS, FMA, SWMFT-Time and SWMFT-FAS decreases from the first to sixth month. These findings are congruent with previous studies [26-30].

Approximately 19% to 26% of observed improvements in the upper extremity of stroke patients is a reflection of time-dependent changes due to spontaneous recovery which lasts for approximately 6 to 10 weeks [26]. Hence, time is a confounding factor when analyzing recovery trajectory in the first 10 weeks. In the present study, the rate of recovery of trunk control and upper extremity remained similar beyond 10 weeks, right up to the end of study period of 6 months. This finding is in agreement with a previous study that demonstrated similarity in the time course of recovery of the trunk and upper extremity [30].

To the best of our knowledge, our study is the first to utilize a mathematical approach to prove that as TIS scores improved over time, FMA improved almost in parallel with the TIS increase. The plots of the gradient of slopes of TIS and FMA recovery curves at each time point showed similar linear decrease, with slope gradient of -0.61 and -0.68 for TIS and FMA respectively (Figure 6). Motor impairment and function of the upper extremity are closely linked [31]. Hence, it is not surprising to observe improvement in SWMFT-Time and SWMFT-FAS as the FMA improved in parallel with TIS over the 6 months. In addition, TIS at each time point was found to be a statistically significant predictor of the outcome of FMA, SWMFT-Time and SWMFT-FAS at 6 months post stroke. Taken together, the findings suggest the existence of an association between trunk control and upper extremity over time, which further affirm the finding of such a relationship in our previous cross-sectional study [5]; and also suggest that trunk control has a significant impact on the recovery of upper extremity impairment and function in the first 6 months post stroke.

We proposed a possible mechanism to explain the concomitant improvement in upper extremity impairment and function as trunk control improves. With recovery of trunk control over time, the trunk stability also improves. A more stable trunk enables better control of movement of the proximal and distal segments of the upper extremity. This is supported by a study that demonstrated significant improvement in functional reach ability of the upper extremity in people with stroke after an intervention consisting of trunk stability exercise [32]. Our findings suggest that trunk stability may have an effect on the stability of the shoulders, which in turn improves the movement of the elbow, wrist and fingers [33]. A stable trunk provides a solid foundation for the torque generated by the extremities [34].

In our study, the results demonstrated different trajectories of the recovery curves of TIS, FMA, SWMFT-Time and SWMFT-FAS based on the severity of the participant's upper extremity and trunk impairment level. Stratification of stroke participants based on the impairment level is important in terms of understanding the recovery pattern and prognostication of outcomes. This will aid clinicians to address the expectations of recovery and counsel them to cope with disability post stroke. Furthermore, the knowledge of different recovery rates is critical in treatment planning and provision of customized therapy to yield the best outcomes.

There are implications for clinical practice based on the novel finding of our study that trunk control is associated with the recovery of upper extremity impairment and function. If the rate of recovery of trunk control can be accelerated, that in turn may have an effect on improving the rate of recovery of the upper extremity, i.e. there may be a cause and effect relationship. Hence, we proposed to test whether, earlier and more intensive trunk rehabilitation, results in better long-term UE function. A focused trunk rehabilitation programme aims to improve the core stability of the trunk and its control, which in turn may have a positive effect on the muscle activation as part of anticipatory postural adjustment (APA). This assumption is supported by the existence of a relationship between trunk muscle activity and upper extremity function [35]. A delay of APA in the muscles on both sides of the body was found in people with stroke [36]. Hence, by improving trunk control in individuals with stroke, it may have the potential to influence upper extremity function and recovery. This notion is supported by findings of our previous study that stabilization of the trunk by an external support enables an improved ability to use the upper extremity for functional activities [5].

Another reason for early and intensive trunk rehabilitation is the strong evidence that trunk control is a significant predictor of overall functional ability, balance and gait after stroke [37-46]. The variance of functional outcome post stroke explained by trunk control ranges from 45% to 71% [37-39]. Hence, trunk control has an impact on many facets of the recovery of people with stroke.

The results of our study must be considered in the light of methodological limitations. All the assessments of the TIS, FMA-UE, SWMFT-Time and SWMFT-FAS were administered by the principal investigator. This may present an element of observer bias even though the intention was to ensure consistency in all assessments.

Future longitudinal and prospective studies may consider using wearable inertial sensors to capture kinematic data of the trunk and upper extremity as these data have been demonstrated to be responsive to change in upper extremity function [47]. Analysis at the kinematic level will enable differentiation between functional gains achieved through compensation versus those achieved through true recovery of motor control [48-51]. Longitudinal kinematic data in addition to clinical outcome measures will provide a comprehensive understanding of neurological recovery post stroke.

CONCLUSION

This longitudinal study has utilized the IGC modelling technique to analyze the recovery pattern of trunk control and upper extremity impairment and function in people with sub-acute stroke. Our work has provided, for the first time, substantial evidence that the pattern of recovery of trunk control is similar to that of recovery of upper extremity following stroke. Upper extremity impairment and function improved in parallel with the improvement in trunk control over the first 6 months post stroke.

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Declaration of Conflicting Interests

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Table 1 Characteristics of subacute stroke participants

Characteristics	Subacute stroke participants (n = 45)
Age (years)	59.2 ± 11.2 range 34 – 84
Sex – Male	26
Female	19
Time since stroke (days)	22.4 ± 15.8 range 7 – 90
Type of stroke – Ischaemic	29
Haemorrhagic	16
Hand dominance – Right	40
Left	5
Affected upper extremity – Right	21
Left	24
Fugl-Meyer Upper Extremity (FMA) score	25.5 ± 20.2 range 4 – 61
Number of participants with FMA	
≤ 20 (Severe impairment)	22
21-50 (Moderate impairment)	17
51-66 (Mild impairment)	6
Trunk Impairment Scale (TIS) score	13.2 ± 4.2 range 3 – 22
Number of participants with TIS	
≤ 10 (Poor trunk control)	13
11-19 (Fair trunk control)	30
≥ 20 (Good trunk control)	2

mean ± standard deviation

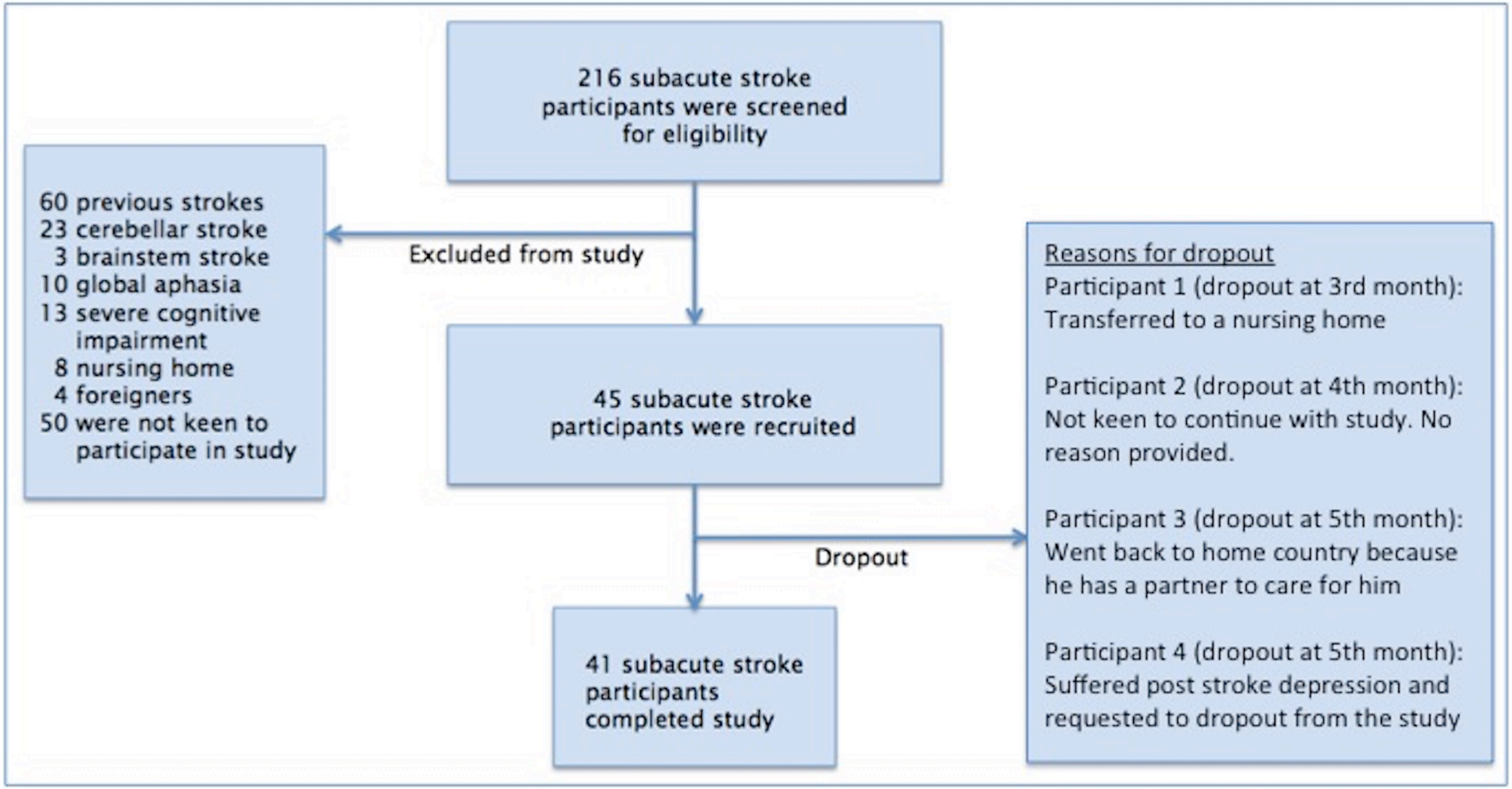


Figure 1 Flowchart of recruitment process and completion of study

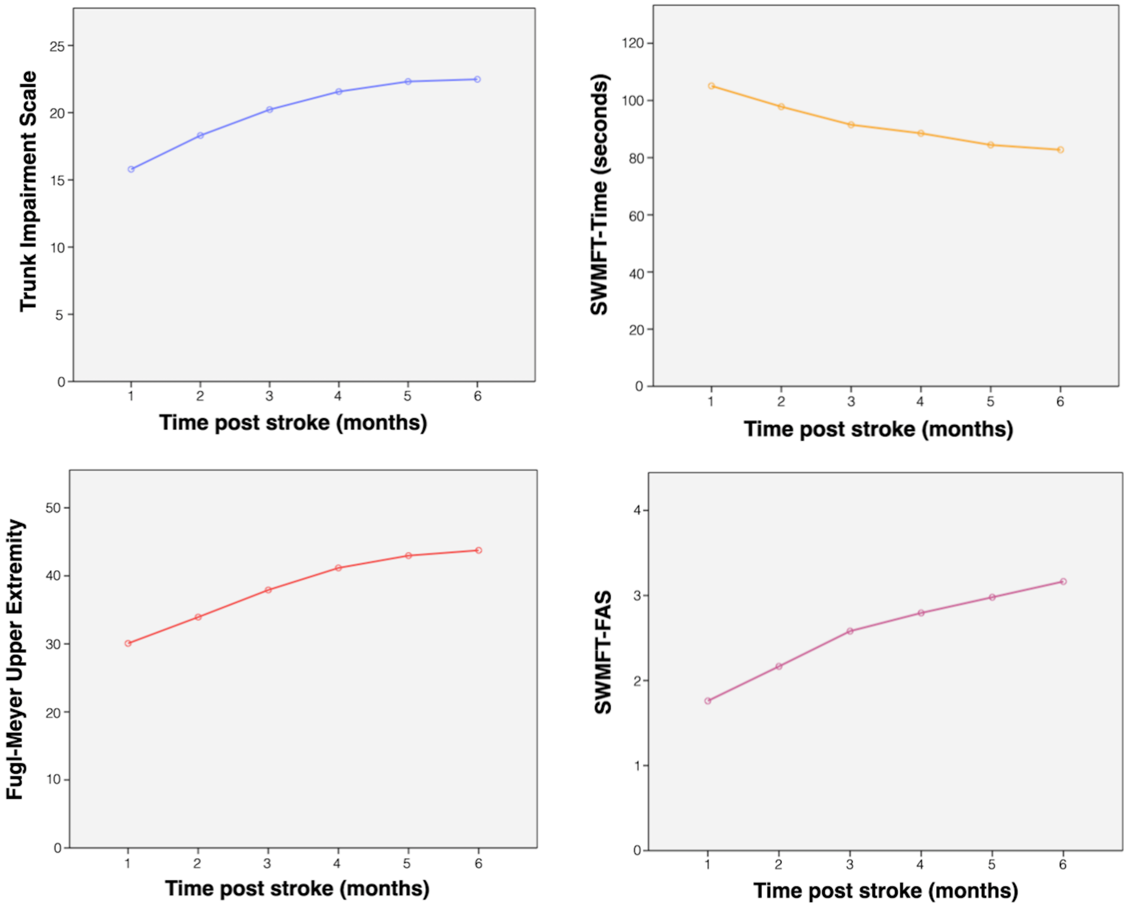


Figure 2 Prototypical plot of the recovery curves of TIS, FMA, SWMFT-Time and SWMFT-FAS

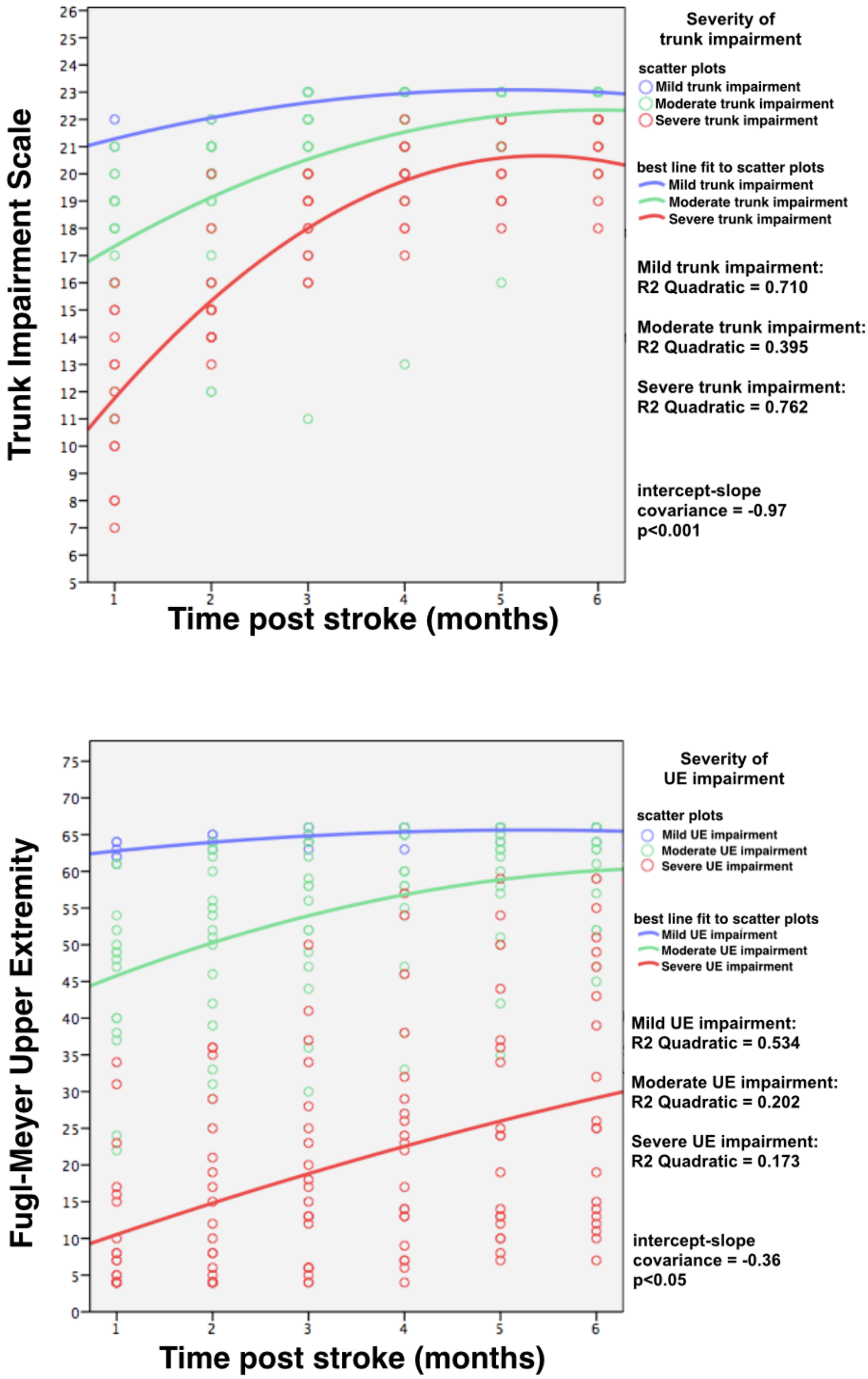


Figure 3 Recovery curves of TIS and FMA based on the initial severity of trunk and upper extremity impairment level

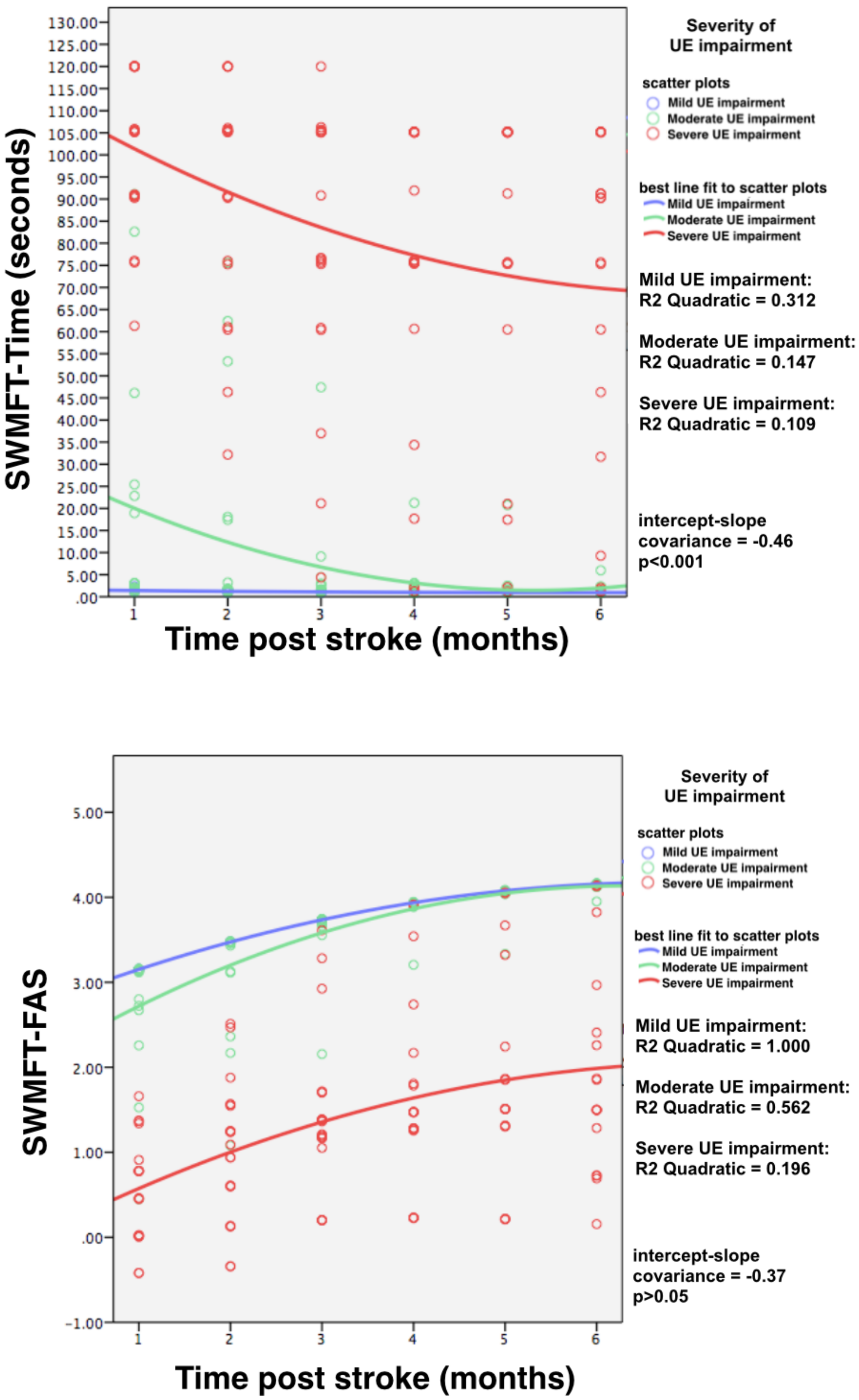
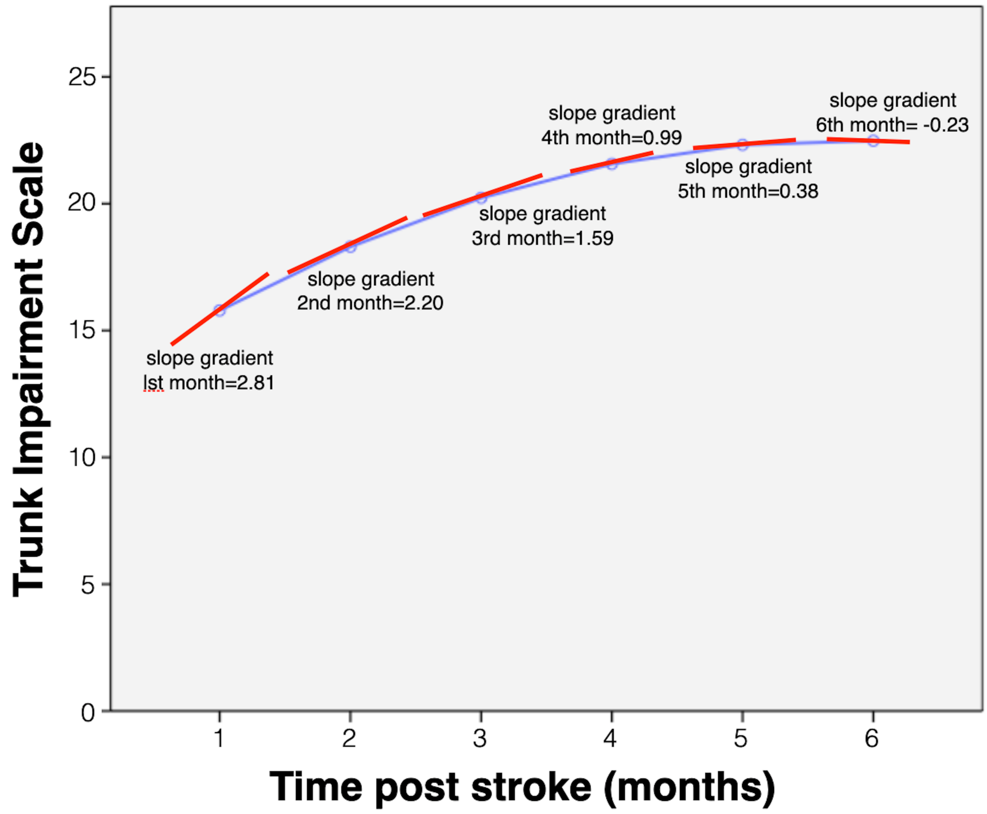


Figure 4 Recovery curves of SWMFT-Time and SWMFT-FAS based on the initial severity of upper extremity impairment level



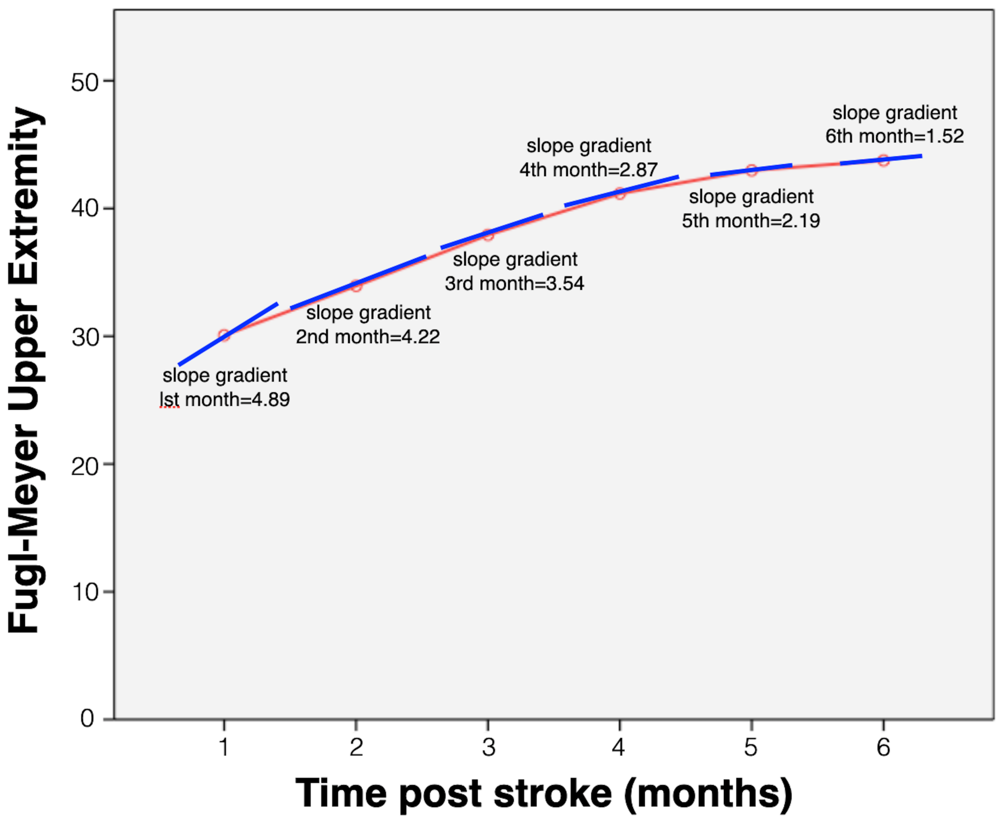


Figure 5 Instantaneous rate of change of the recovery curves of TIS and FMA

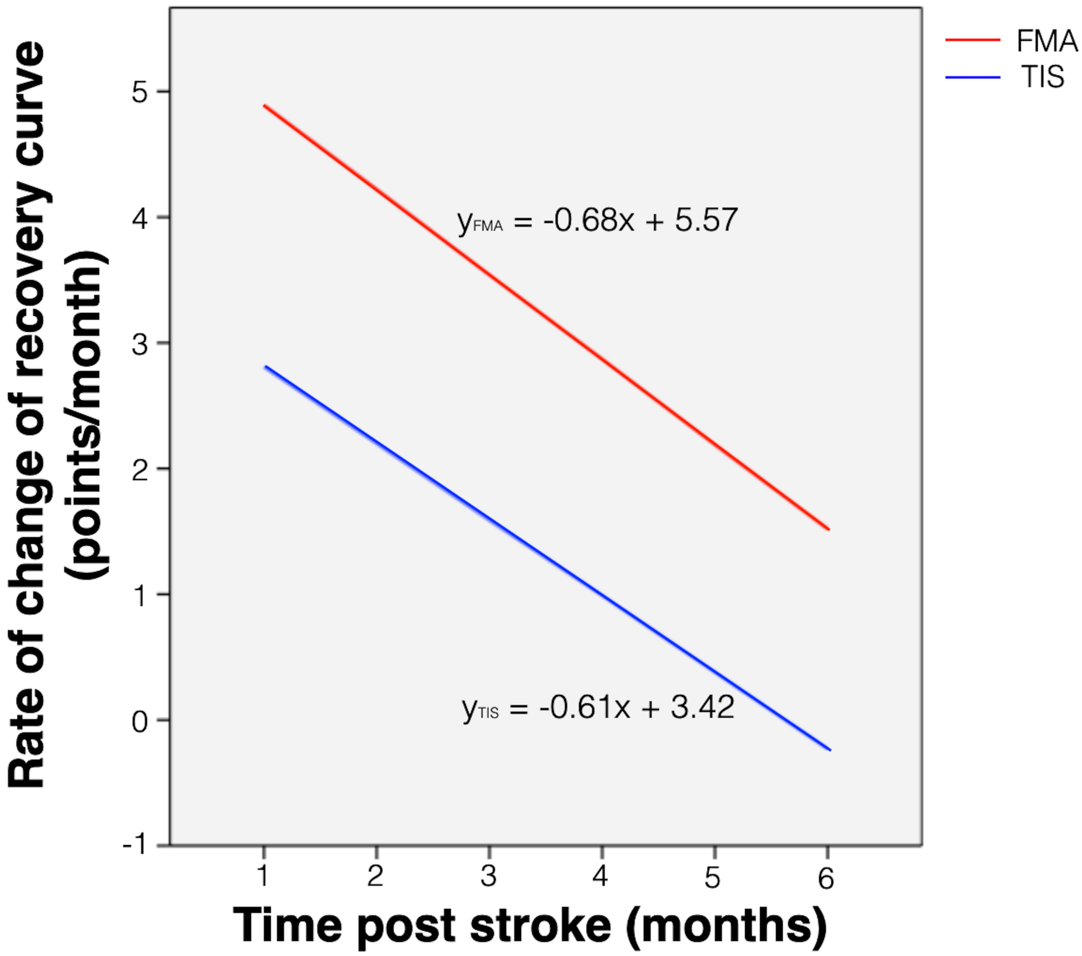


Figure 6   Plot of the rate of change of the recovery curves of TIS and FMA over time

Appendix I Effect of predictors on the TIS model

Predictors	Conditional quadratic model	
	F statistic	p value
Age	0.13	0.721
Age x TIME (linear slope)	1.62	0.205
Age x TIME x TIME (quadratic slope)	2.74	0.100
Gender	0.001	0.974
Gender x TIME	0.29	0.591
Gender x TIME x TIME	0.35	0.557
Hand dominance	0.02	0.898
Hand dominance x TIME	0.003	0.960
Hand dominance x TIME x TIME	0.001	0.997
Affected UE	0.78	0.383
Affected UE x TIME	0.10	0.751
Affected UE x TIME x TIME	0.01	0.923
Time post stroke	38.55***	0.001
Time post stroke x TIME	27.42***	0.001
Time post stroke x TIME x TIME	9.45**	0.002
Stroke type	7.08*	0.011
Stroke type x TIME	32.46***	0.001
Stroke type x TIME x TIME	26.53***	0.001
Severity of UE impairment	22.12***	0.001
Severity of UE impairment x TIME	10.08**	0.002
Severity of UE impairment x TIME x TIME	2.12	0.147
Severity of trunk impairment	26.02***	0.001
Severity of trunk impairment x TIME	34.62***	0.001
Severity of trunk impairment x TIME x TIME	19.02***	0.001
Therapy Time	0.20	0.659
Therapy Time x TIME	0.03	0.869
Therapy Time x TIME x TIME	0.06	0.811

***p<0.001; **p<0.01; *p<0.05

Appendix II: Effect of predictors on the FMA model

Predictors	Conditional quadratic model	
	F statistic	p value
Age	0.92	0.343
Age x TIME (linear slope)	8.47**	0.004
Age x TIME x TIME (quadratic slope)	8.06**	0.005
Gender	0.26	0.614
Gender x TIME	0.14	0.712
Gender x TIME x TIME	0.40	0.527
Hand dominance	0.14	0.708
Hand dominance x TIME	0.62	0.433
Hand dominance x TIME x TIME	1.63	0.204
Affected UE	0.03	0.862
Affected UE x TIME	9.34**	0.003
Affected UE x TIME x TIME	7.38**	0.007
Time post stroke	7.63**	0.008
Time post stroke x TIME	0.001	0.992
Time post stroke x TIME x TIME	1.12	0.291
Stroke type	2.65	0.111
Stroke type x TIME	0.48	0.490
Stroke type x TIME x TIME	0.22	0.639
Severity of UE impairment	149.34***	0.001
Severity of UE impairment x TIME	4.97**	0.027
Severity of UE impairment x TIME x TIME	0.30	0.584
Severity of trunk impairment	14.02***	0.001
Severity of trunk impairment x TIME	0.23	0.631
Severity of trunk impairment x TIME x TIME	4.67*	0.032
TIS score	3.72	0.055
TIS score x TIME	16.23***	0.001
TIS score x TIME x TIME	9.30**	0.003
Therapy Time	1.24	0.268
Therapy Time x TIME	3.10	0.080
Therapy Time x TIME x TIME	4.37*	0.038

***p<0.001; **p<0.01; *p<0.05

Appendix III: Effect of predictors on the SWMFT-Time model

Predictors	Conditional quadratic model	
	F statistic	p value
Age	0.43	0.515
Age x TIME (linear slope)	3.18	0.077
Age x TIME x TIME (quadratic slope)	4.06*	0.045
Gender	0.23	0.635
Gender x TIME	0.07	0.793
Gender x TIME x TIME	0.15	0.698
Hand dominance	0.25	0.621
Hand dominance x TIME	0.42	0.519
Hand dominance x TIME x TIME	0.37	0.541
Affected UE	0.004	0.952
Affected UE x TIME	17.86***	0.001
Affected UE x TIME x TIME	16.11***	0.001
Time post stroke	10.35**	0.002
Time post stroke x TIME	16.74***	0.001
Time post stroke x TIME x TIME	12.21***	0.001
Stroke type	3.49	0.068
Stroke type x TIME	7.11**	0.008
Stroke type x TIME x TIME	4.11*	0.047
Severity of UE impairment	114.72***	0.001
Severity of UE impairment x TIME	7.80**	0.006
Severity of UE impairment x TIME x TIME	1.29	0.258
Severity of trunk impairment	17.73***	0.001
Severity of trunk impairment x TIME	1.24	0.268
Severity of trunk impairment x TIME x TIME	0.44	0.509
TIS score	13.55***	0.001
TIS score x TIME	0.24	0.628
TIS score x TIME x TIME	15.77***	0.001
FMA score	647.10***	0.001
FMA score x TIME	9.19**	0.003
FMA score x TIME x TIME	5.88*	0.016
Therapy Time	0.06	0.809
Therapy Time x TIME	0.004	0.948
Therapy Time x TIME x TIME	0.01	0.916

***p<0.001; **p<0.01; *p<0.05

Appendix IV: Effect of predictors on the SWMFT-FAS model

Predictors	Conditional quadratic model	
	F statistic	p value
Age	0.50	0.483
Age x TIME (linear slope)	5.32	0.022
Age x TIME x TIME (quadratic slope)	4.22*	0.041
Gender	0.01	0.906
Gender x TIME	0.88	0.349
Gender x TIME x TIME	0.66	0.420
Hand dominance	0.01	0.755
Hand dominance x TIME	0.22	0.638
Hand dominance x TIME x TIME	0.39	0.532
Affected UE	0.09	0.765
Affected UE x TIME	11.77***	0.001
Affected UE x TIME x TIME	5.40*	0.021
Time post stroke	8.82**	0.005
Time post stroke x TIME	0.97	0.326
Time post stroke x TIME x TIME	0.01	0.915
Stroke type	2.37	0.131
Stroke type x TIME	0.89	0.348
Stroke type x TIME x TIME	0.31	0.582
Severity of UE impairment	149.57***	0.001
Severity of UE impairment x TIME	1.52	0.219
Severity of UE impairment x TIME x TIME	0.10	0.754
Severity of trunk impairment	16.35**	0.001
Severity of trunk impairment x TIME	0.37	0.546
Severity of trunk impairment x TIME x TIME	0.04	0.852
TIS score	8.15**	0.005
TIS score x TIME	2.04	0.155
TIS score x TIME x TIME	6.75**	0.010
FMA score	1083.77***	0.001
FMA score x TIME	0.02	0.890
FMA score x TIME x TIME	1.49	0.225
SWMFT-Time	254.56***	0.001
SWMFT-Time x TIME	14.60	0.001
SWMFT-Time x TIME x TIME	1.99	0.160
Therapy Time	0.01	0.943
Therapy Time x TIME	0.38	0.537
Therapy Time x TIME x TIME	0.95	0.331

***p<0.001; **p<0.01; *p<0.05