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RPSS Responsiveness Highlights

- RPSS uses observational kinematics to assess motor compensations during reaching.
- RPSS responsiveness was assessed in 567 subjects with acute-to-chronic stroke.
- RPSS had high internal responsiveness.
- RPSS had moderate external responsiveness with upper limb impairment scores.
- RPSS can distinguish between motor restitution and compensation in stroke recovery trials.

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Sandeep K. Subramanian, PT, PhD[1], Gita Margolese[2,3], Andrea Turolla, PT, PhD[4,5], Gustavo Saposnik, MSc, MD[6], Mindy F. Levin, PT, PhD[2,3]

[1]Departments of Physical Therapy, Physician Assistant Studies and Rehabilitation Medicine, UT Health San Antonio, San Antonio, Texas, USA
[2]School of Physical and Occupational Therapy, McGill University, Montreal, Quebec. Canada
[3]Centre for Interdisciplinary Research in Rehabilitation, Montreal, Quebec. Canada
[4]Department of Biomedical and Neuromotor Sciences, University of Bologna, Bologna, Italy
[5]Laboratory of Rehabilitation Technologies, Hospital San Camillo IRCCS, Venice, Italy
[6]Stroke Outcomes and Decision Neuroscience Unit, Toronto, Unity Health Toronto, University of Toronto, Ontario, Canada

ORCIDs:
Sandeep K Subramanian: 0000-0002-5972-1588
Andrea Turolla: 0000-0002-1609-8060
Gustavo Saposnik: 0000-0002-5950-9886
Mindy F Levin: 0000-0002-8965-7484

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Address correspondence to:
Mindy F. Levin, PT, PhD
School of Physical and Occupational Therapy
McGill University
3654 Promenade Sir William Osler
Montreal, Quebec, Canada. H3G 1Y4
Mindy.levin@mcgill.ca

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ABSTRACT

Objective: The objective of the study was to estimate the internal and external responsiveness of the Reaching performance Scale for Stroke (RPSS) in individuals with stroke.

Design: Retrospective analysis of data from four randomized controlled trials.

Setting: Recruitment locations spanning rehabilitation centers and hospitals in Canada, Italy, Argentina, Peru, and Thailand.

Participants: Data from 567 participants (acute to chronic stroke) was available.

Interventions: All four studies involved training using virtual reality for upper limb rehabilitation.

Main outcome measures: RPSS and upper extremity Fugl-Meyer Assessment (FMA-UE) scores. Responsiveness was quantified for all data and across different stages of stroke. Internal responsiveness of the RPSS was quantified as effect-sizes calculated using post and pre-intervention change data. External responsiveness was quantified using orthogonal regressions between FMA-UE and RPSS scores. The area under the Receiver Operating Characteristic curve

(AUC) was quantified based on the ability of RPSS scores to detect change above FMA-UE minimal clinically important different values across different stages of stroke.

Results: The RPSS had high internal responsiveness overall and across the acute/subacute and chronic stages of stroke. For external responsiveness, orthogonal regression analyses indicated that change in FMA-UE scores had positive moderate correlations with both RPSS Close and Far Target scores for all data and across the acute/subacute and chronic stages of stroke (0.6<r<0.7). The AUC was acceptable for both targets (0.65<AUC values<0.8) across the acute/subacute and chronic stages.

Conclusion: In addition to being reliable and valid, the RPSS is also responsive. Along with the FMA-UE, using RPSS scores can help present a more comprehensive picture of motor compensations to characterize post-stroke upper limb motor improvement.

Key Words: Movement quality, reaching, upper limb, compensation, restitution/true recovery, cerebrovascular accident, outcomes

List of abbreviations:

AUC = Area Under the Curve

CMSA = Chedoke-McMaster Stroke Assessment

COSMIN (COnsensus-based Standards for the selection of health status Measurement INstruments)

ES = Effect Size

EVREST = Effectiveness of Virtual Reality Exercises in STroke

ICC = Interclass Correlation Coefficient

IRCCS = Institute of Hospitalization and Care of a Scientific Nature

RPSS responsiveness

FMA-UE = Fugl-Meyer Assessment of the Upper Extremity

It-NIHSS = Italian version of the National Institutes of Health Stroke Scale

JRH = Jewish Rehabilitation Hospital

MCID = Minimal clinically important difference

MDC = Minimal detectable change

ROC = Receiver Operating Characteristic

SRM = Standard Response Mean

RPSS = Reaching Performance Scale for Stroke

SPSS = Statistical Package for Social Sciences

TRIPOD = Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis

UT = University of Texas

Stroke is a major cause of disability often impacting physical, psychological and cognitive function, leading to limitations in activity and social participation.[1] A common impairment is upper limb (UL) paresis, affecting up to 80% of patients and persisting into the chronic stage in more that 65% of cases despite prolonged rehabilitation.[2] UL paresis is characterized by muscle weakness, altered muscle tone, decreased sensation and impaired control of voluntary movement[3] and is often accompanied by an increased use of arm and trunk compensatory movements.[4,5] When possible, however, use of compensatory movements should be discouraged since it may lead to learned non-use, learned bad-use and/or pain, decreasing recovery potential and contributing to persistent impairment.[6,7] Thus, it is important to distinguish between motor restitution/true motor recovery and compensation during rehabilitation.

Current UL interventions may not be achieving the patient's true motor recovery potential.[8,9] This may be related to the intervention itself or to inadequacies of clinical outcome measures to distinguish between levels of restitution/true recovery and compensation.[10-13] For example, even if an intervention results in a significantly increased joint range, improvement may not be recorded if the outcome measure only quantifies task accomplishment without accounting for task performance (i.e., movement quality). This is the case of the Fugl-Meyer Assessment of the Upper Extremity (FMA-UE). Although suggested as the gold-standard[14] for UL motor impairment assessment, it assesses in- and out-of-synergy movement while not accounting for the use of motor compensations.[15] In contrast, kinematic analysis can provide information on movement quality[15] and more accurately identify changes in motor impairment levels, even in chronic stroke.[16,17] However, kinematic analysis is not widely used in clinical settings due its complexity, cost and time constraints. The advantage of the Reaching

Performance Scale for Stroke (RPSS)[18-20] is that it relies on observational movement analysis[21] instead of sophisticated motion analysis equipment to measure motor elements associated with restitution/true recovery and compensation during reaching.

The RPSS assesses UL and trunk movement patterns and compensatory shoulder and trunk movements during two standardized midline reach-to-grasp tasks to a Close (within the participant's arm length) and a Far Target (1-1/3 times arm length).[18-20] Only the reaching and grasping components of the task are assessed and not functional aspects of object manipulation. Five movement pattern components (trunk displacement, endpoint movement smoothness, shoulder and elbow movement, prehension) and a global score are each rated on 4-point (0-3pt) ordinal scales for a total of 18pts per target. A score of 0 indicates excessive compensatory forward trunk movement, lack of endpoint smoothness, decreased or no shoulder/elbow movement, or inability to complete the task. Conversely, a score of 3 indicates no compensatory trunk movement, smooth arm/trunk movements, full shoulder/elbow joint movements, or ability to easily complete the task.

Test development and analysis of psychometric properties (test-retest reliability, measurement error, concurrent and discriminant validity) have been reported.[18-20] RPSS has excellent intra-rater (ICC=1.00), inter-rater (ICC≥0.98)[19] and test-retest reliability (ICC, Close Target=0.98; Far Target=0.98)[20] as well as high concurrent validity with the FMA-UE (Spearman's rho≥0.88).[19] Using a cut-off score of 50pts to distinguish between mild and moderate-severe stroke,[15] RPSS discriminated between these groups with cut-off values of 15.5pts and 14.0pts for Close and Far Targets respectively.[20] RPSS scores also predicted functional performance, with the elbow component of the Close Target test predicting behavior on 3 items of the Wolf Motor Function Test,[22] based on independently validated study samples.[23]

It is essential that outcome measures correctly identify changes in the underlying condition. According to the COSMIN (COnsensus-based Standards for the selection of health status Measurement INstruments) statement, responsiveness is “the ability of an instrument to detect change over time in the construct to be measured”.[24] This is relevant when it is used longitudinally to monitor health conditions or assess intervention effects. Responsiveness is a key factor along with reliability and validity for any outcome measure. It is also essential to assess both internal (ability to assess change over a pre-specified period) and external (correspondence of change in the outcome under study with corresponding change in a related measure) outcome responsiveness.[25,26]

The study objective was to determine RPSS responsiveness in participants in the acute-to-chronic phases after stroke. For internal responsiveness, since RPSS objectively quantifies UL kinematics and changes in kinematics have been positively correlated with decreases in clinical impairment,[17,27] we hypothesized that changes in RPSS scores would accurately reflect changes in UL sensorimotor impairment in patients with stroke after training. Since the amount of therapy is related to changes in UL kinematics,[28] we also hypothesized that the amount of change in RPSS scores would be related to the amount of therapy received by the patient. With respect to external responsiveness, we hypothesized that changes in RPSS scores would be related to changes in the level of UL impairment with training[27,28] and that this would be similar for patients with different chronicity levels.

METHODS

We performed a secondary analysis of data from four randomized controlled trials conducted between 2006 and 2020 in which RPSS was measured as an outcome (Supplemental

Appendix 1). One trial[29] was a 2-week (600min) multisite randomized controlled trial of 141 participants with sub-acute stroke from 14 in-patient stroke rehabilitation units in four countries (Canada, Argentina, Peru, Thailand) comparing exergaming in virtual reality to recreational activities (EVREST-NTC692523). Two trials were 4-week (2100min) long trials (MOSE-NCT03530358; MAVASI-NCT02234531) that included 421 participants with acute-to-chronic stroke at a research hospital in Venice, Italy.[30-32] The fourth trial compared two 4-week long UL training approaches of equal intensity (540mins)[33] in 32 participants with chronic stroke (ACTRN12611000858998) in Montreal, Canada. The overall sample included 567 participants.

Selection Criteria

For each study, participants were ≥18 years old and were either in the acute-to-subacute or chronic stage of stroke. Participants had i) sustained a first-time ischaemic or hemorrhagic stroke and ii) mild-moderate motor disability (Chedoke-McMaster Stroke Assessment (CMSA)[34] stage ≥3/7 [EVREST; JRH] or Motor Arm sub-score between 1-3 on the Italian version[35] of the National Institutes of Health Stroke Scale (It-NIHSS: MOSE, MAVASI). Participants were excluded if they were i) medically unstable (EVREST); ii) unable to follow instructions; iii) participating in another trial or receiving rehabilitation services; or had iv) moderate cognitive decline (Mini Mental State Examination score <20/30 points); v) brainstem/cerebellar lesions (JRH); vi) severe verbal comprehension deficit, apraxia or neglect interfering with UL movements and object manipulation; vii) behavioural disturbances (e.g., aggressiveness, severe depression/apathy) affecting compliance with rehabilitation programs; or viii) any other condition that could put the patient at risk (e.g., shoulder pain, fracture). Participants signed informed consent forms approved by the local Institutional Ethics Committees. Similar clinical and demographic information were collected for all studies and included sex, lesion location, age, chronicity, and UL impairment scores.

Outcome measures

RPSS[18] and FMA-UE[36] were recorded for all participants at baseline and at the conclusion of a treatment intervention (post-test) with a mean of 29 ±7 days between baseline and post-test.

RPSS

A textured cardboard cone was used as the target in both RPSS reach-to-grasp tasks. Five movement pattern components were rated on 4pt ordinal scales (0-3) for a total of 18pts/target. A higher score on RPSS represents a higher level of restitution/ true recovery and less compensatory movement.

FMA-UE

The FMA-UE scale is the gold standard UL motor impairment assessment, which assesses reflex function, movement in- and out-of-synergies and coordination.[36] Scoring is based on a three-point ordinal scales from 0-2pts for a total of 66pts. Lower scores denote greater UL motor impairment.

Statistical Analysis

Descriptive statistics highlighted main demographic characteristics using SPSS v26 and Minitab v17. Change scores for FMA-UE and RPSS Close and Far Targets were used. Internal responsiveness was computed using the standard response mean as an effect-size (ES) estimate[26] and characterized as small (0.08–0.18), medium (0.19–0.40) and large (≥0.41).[37]

External responsiveness was estimated using two methods. Correlations between changes in RPSS scores for both targets with changes in FMA-UE scores (Anchor-based method) were assessed initially using orthogonal regression. An orthogonal regression was the preferred approach as both the dependant and independent variables can have some error.[38] Changes in FMA-UE scores above MDC_{90} values were also correlated with changes in RPSS scores to both targets. Given that FMA-UE does not account for movement quality,[12,15] this analysis was done to assess the types of movement patterns used by individuals with changes greater than available MDC_{90} values in FMA-UE scores.

Correlations were classified as mild (≤0.39), moderate (0.40–0.69), or strong (≥0.70).[39] The probability of RPSS scores of both targets to correctly classify participants with change (sensitivity) or no change (specificity) greater or equal to the minimal clinically important difference (MCID) values of FMA-UE was estimated. These values were used to plot the Receiver Operating Characteristic (ROC) curves from which the area under the curve (AUC) was quantified. Since MCID values differ for the acute-to-subacute (10.2pts)[40] and chronic (5.25pts)[41] stages of stroke, separate analyses were conducted. Values of AUC between 0.65-0.79, 0.80-0.89 and ≥0.90 were considered acceptable, good, and excellent, respectively.[42]

RESULTS

Data from 567 participants (Table 1) were available for RPSS responsiveness assessment scores for both targets.

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Internal responsiveness:

RPSS scores for both targets had large effect-sizes: Close (ES=0.573); Far (ES=0.565). Exploratory analyses examined if responsiveness differed according to stroke chronicity and treatment intensity (defined by treatment duration in minutes). Effect-sizes were large for those with acute-to-subacute stroke for both Close (ES=0.610) and Far (ES=0.662) Targets as well as for participants with chronic stroke for both Close (ES=0.550) and Far (ES=0.486) Targets. With respect to intervention duration ≤600 minutes,[29,33] large effect-sizes (Close:0.554, Far:0.510) were obtained. These effect-sizes were similar in studies providing 2100 minutes[30-32] of therapy (Close:0.580, Far:0.583).

External responsiveness:

For all 567 participants, changes in FMA-UE scores were moderately correlated with both RPSS Close (r=0.664; Fig. 1A) and Far Target (r=0.673; Fig. 1B) scores. Further exploratory analyses revealed a strong correlation with RPSS Close (r=0.768; Fig. 1C) and Far Target (r=0.775; Fig. 1D) scores when change scores above MDC_{90} (3.2 points)[43] values in FMA-UE scores were considered.

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Regarding the effects of stroke chronicity on external responsiveness, for the 250 participants with subacute stroke, similar correlations between RPSS Close (r=0.690) and Far Target (r=0.686) scores with FMA-UE change scores were obtained (Table 2). When change scores above MDC_{90} values in FMA-UE scores in the acute-to-subacute stage were considered (3.6pts),[44] there was a strong correlation with RPSS Close (r=0.793) and Far Target (r=0.750) scores. ROC curves were plotted with change values for participants with changes higher than FMA-UE MCID scores in the acute-subacute stages (n=45). The AUC for the Close Target (Fig. 2A) was 0.717 (95% CI:0.625-0.808, p<0.001) and for the Far Target (Fig. 2B) was 0.787 (95% CI:0.711-0.863, p<0.001).

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For the 317 participants with chronic stroke, moderate positive correlations were obtained for RPSS Close (r=0.639) and Far Target (r=0.659) scores with FMA-UE change scores (Table 2). When change scores above FMA-UE MDC_{90} values (3.2pts) in FMA-UE scores were considered, there were moderate correlations with both RPSS Close (r=0.652) and Far Target (r=0.637) scores. ROC curves were plotted for those participants with change scores higher than FMA-UE MCID in the chronic stages (n=117). The AUC for the Close Target (Fig. 2C) was 0.670 (95% CI:0.607-0.732; p<0.001) and for the Far Target (Fig. 2D) was 0.651 (95% CI: 0.586-0.715; p<0.001).

The groups receiving 600 and 2100mins of treatment included participants across all stroke stages. However, due to the absence of a universally established MDC_{90} value for FMA-UE scores across all chronicity levels, we could not analyze external responsiveness in terms of treatment intensity.

DISCUSSION

Internal and external responsiveness of RPSS to measure changes in patients with acute-to-subacute and chronic stroke participating in intensive UL task-specific practice were assessed. To our knowledge, this is one of the largest studies assessing RPSS internal and external responsiveness. RPSS had high internal responsiveness and moderate-to-strong external responsiveness.

Internal responsiveness was high for both targets. Our results are similar to those obtained in other studies using interventions involving auditory feedback[45] and motor imagery.[46] Effect-sizes did not differ with task-practice intensity or stroke chronicity and were large for ≤600 and 2100mins and for the acute-subacute and chronic stages. Results provide preliminary evidence that the observed effects exceed the MCID value, assuming a standard ES of ≥0.2 as a preliminary MCID.[47] Future studies should assess whether MCID values change using subjective ratings of utility of change.

A recent consensus statement about core recommendations for tracking recovery after stroke recommended adding kinematics as standardized measurements in stroke trials.[13] The high RPSS responsiveness levels are an essential addition to its existing robust psychometric properties and support its use to quantify movement quality in some clinical settings. Thus, RPSS is a potential core outcome measure to investigate changes in movement quality following UL rehabilitation, as a good substitute to instrumented kinematic analysis, which is a major advantage for clinicians considering the limited time and resources in clinical settings.

The similar effect-sizes obtained despite provision of different rehabilitation intensities can be attributed in part to pre-intervention floor and/or ceiling effects as well as intervention specificity. However, we found no floor effects for either participant group. For the group receiving ≤600mins of practice, pre-intervention ceiling effects were 29.7% (Close Target) and 19.7% (Far Target). For the group receiving 2100mins of practice, pre-intervention ceiling effects for the Close and Far Targets were 21.4% (Close Target) and 16.9% (Far Target). The ceiling effects for the Far Target scores are within the acceptable range of ≤20%.[48] However, for the Close Target, they marginally exceed the acceptable amount for both intensities. Nevertheless, effect-sizes were similar. Thus, it is unlikely that floor and/or ceiling effects contributed to the similar magnitude of effect-sizes in this study. Effects of other factors including patient characteristics and lesion location may be explored in future studies.

Intensity of task-practice was defined as time spent in therapy.[49] Additional task-practice intensity metrics are perceived exertion rate during task performance[49] and number of repetitions performed.[50] Information on the number of repetitions was provided in only one study (72 repetitions/session)[33] which resulted in a large effect-size for the Close Target score (SRM=0.42) and a moderate effect-size for the Far Target score (SRM=0.26). Whether RPSS responsiveness to both targets differs by the number of movement repetitions/session and the total number of sessions remains unknown. This information can help further explain the utility of RPSS as a suitable assessment across all stroke stages. However, floor (no significant floor effects) and ceiling effects (significant only for Close Target) suggest that RPSS Far Target scores can be used across all stroke stages and practice intensities, while RPSS Close Target scores may be useful in about 70% of the population.

Change scores to both targets were moderately correlated with FMA-UE change scores, with large associations only for participants with acute-to-subacute stroke when changes above the MDC_{90} value (≥3.6pts)[44] were considered. The FMA-UE has been used as the measure of choice in other studies for similar reporting of responsiveness using the anchor-based method.[17,47] The moderate correlations for the whole dataset as well as for participants with chronic stroke were expected since FMA-UE and RPSS focus on different movement aspects. FMA-UE primarily assesses the ability to accomplish UL motor elements in- and out- of stereotypical synergies seen after stroke, without a specific functional goal. On the other hand, RPSS assesses the ability to combine UL and trunk degrees of freedom in a functional synergy to achieve a particular reaching and grasping goal. UL motor recovery can extend well into the chronic stages of stroke[51] with or without a plateau,[52] and provision of task-specific practice contributes to the enhancement of UL motor recovery.[16,33,45,46] Based on evidence of improvement in RPSS scores, our study suggests that restitution/true recovery in the chronic stage can involve an improved ability to functionally exploit the system's kinematic abundance by combining different joint rotations without using motor compensations. Thus, one avenue of restitution/true recovery potentially involves better exploitation of joint redundancy or abundance in the system[53,54] for successful task performance.

Few participants with change scores above the MDC_{90} value in FMA-UE values had negative changes in RPSS scores for Close and Far Targets (Fig. 1A,1B). These findings support previous results that improvements in FMA-UE scores do not distinguish whether motor improvement was achieved using compensations or pre-morbid movement patterns.[10,15] Additional support for these previous results is provided by i) the moderate correlations with changes in FMA-UE scores greater than MDC_{90} values in chronic stroke (Table 2) and ii) acceptable AUC values in the acute/subacute and chronic stages. The RPSS fills a gap in identifying motor compensations and UL movement quality during reaching that is not addressed in clinical motor impairment and activity scales.[12,55] These results support previous suggestions that more than one outcome may be necessary to completely characterize post-stroke UL motor improvement.[12] Indeed, we may require additional clinical tools to identify whether and how compensatory movements are incorporated into UL tasks. The RPSS measures one such task, but more task analysis scales may be needed to fully appreciate the relationship between compensation use and clinical improvement.

Limitations

The heterogeneity in types of training between studies may have influenced the extent of responsiveness of the measure. In addition, use of CMSA in Canada and It-NIHSS as inclusion criteria may be a confounding factor. Future studies should consider a minimal set of common inclusion criteria. Only one study[33] had a retention assessment. Thus, responsiveness changes at retention remain to be estimated. Finally, other factors such as age, sex, handedness, lesion site, cognition and sensation that may have affected results were not considered in the present analysis.

CONCLUSIONS

In addition to being reliable and valid,[18-20] the RPSS was found to be responsive. Our results support the use of RPSS to clinically assess movement quality during reaching tasks, in lieu of sophisticated kinematic analysis. In addition to FMA-UE scores, RPSS scores can help present a more comprehensive picture of post-stroke UL motor improvement, by determining whether activity improved due to restitution/true recovery or compensation. Further research should consider patient stratification according to prognostic factors of true UL recovery, to determine if RPSS psychometrics vary with recovery potential.

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Figure Legends:

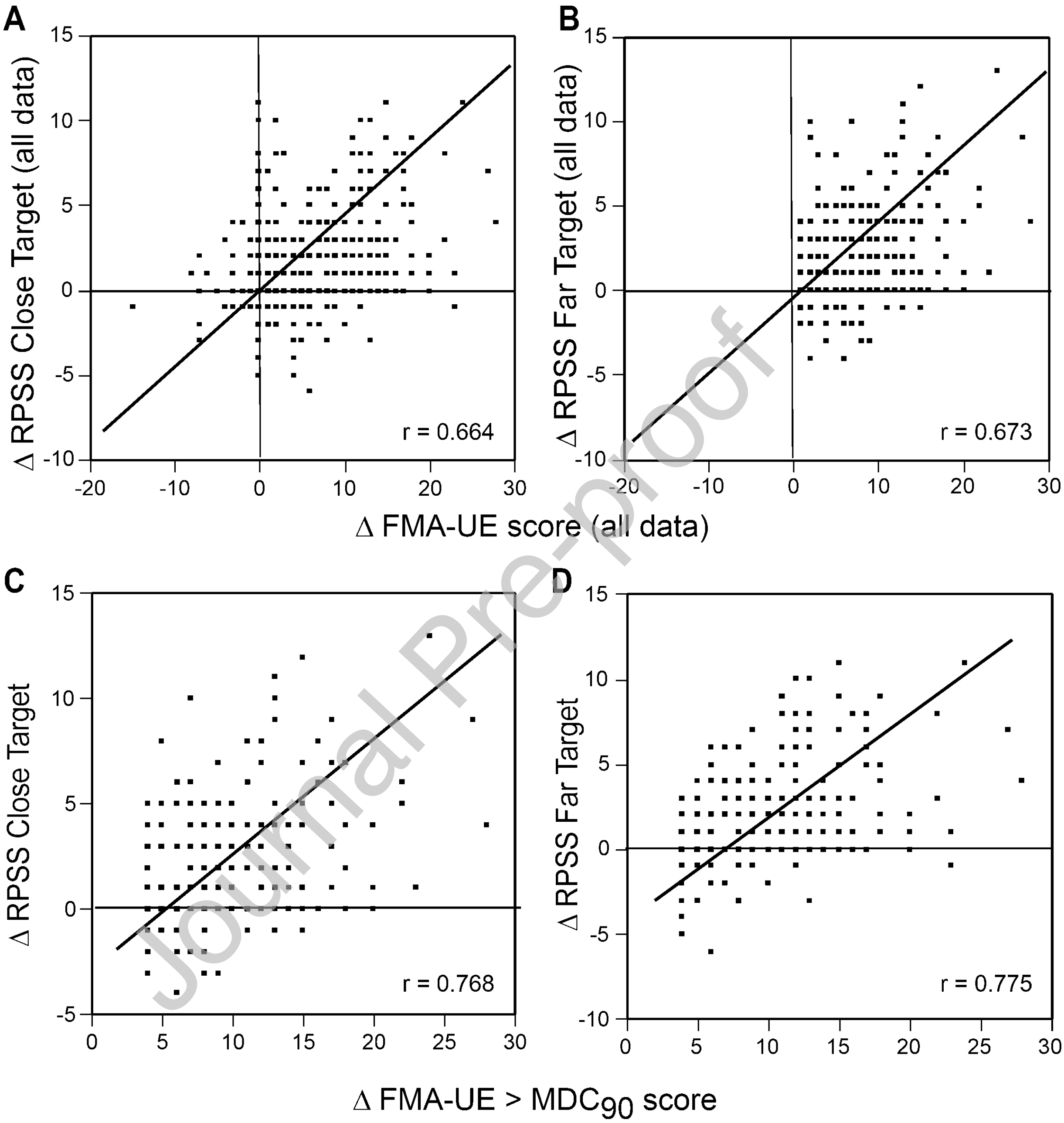

Figure 1

RPSS responsiveness

Figure 1. Scatterplots of the association between upper extremity Fugl-Meyer scores (FMA-UE) and the RPSS Close (A) and Far Target (B) change scores. Panels A and B include all data, Panels C and D include only data with FMA-UE change scores greater than the Minimal Clinical Difference (MCD_{90}) of 3.2 points.

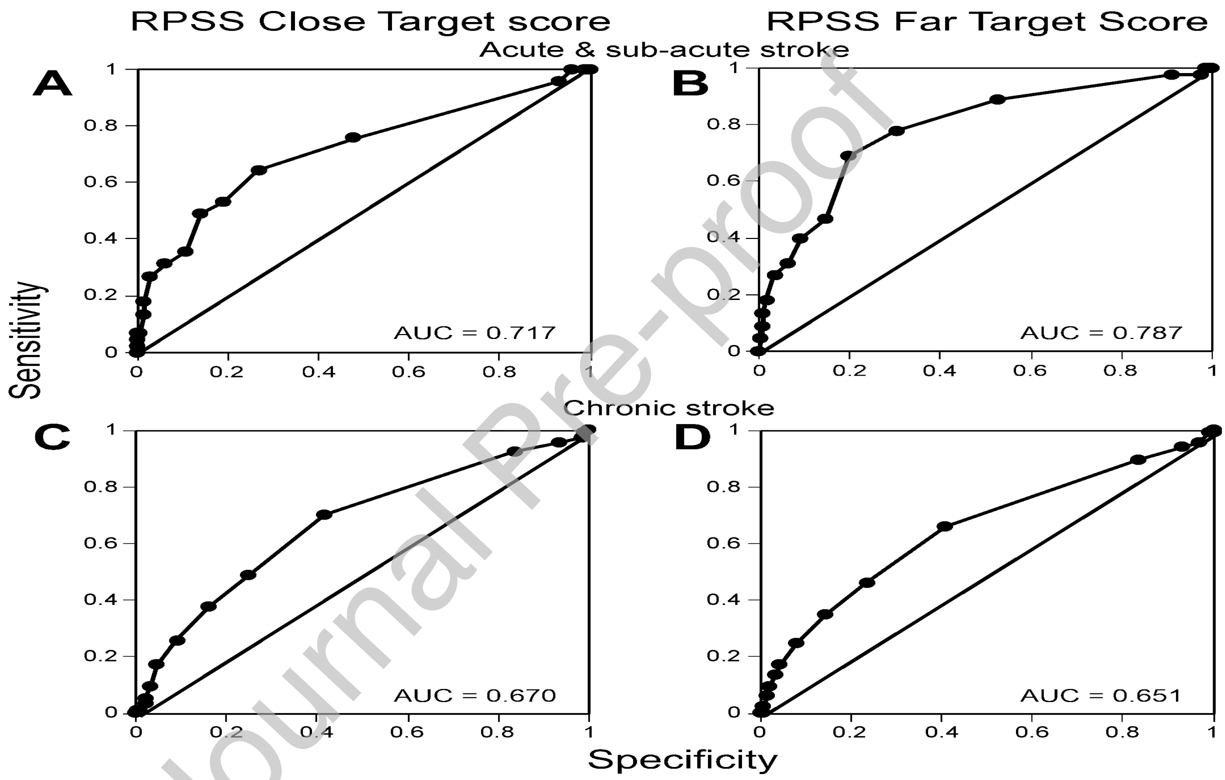

Figure 2

Figure 2. Receiver Operating Characteristic Curves for the Reaching Performance Scale for Stroke (RPSS) Close (A,C) and Far (B,D) Target scores for acute and sub-acute (A,B) and chronic stages (C,D) of stroke.

Table 1: Demographics of participants in the four trials.

	Number of participants (%)/Mean (95%CI)		
	All participants (n=567)	Acute and sub-acute stroke (n=250)	Chronic stroke (n=317)
Gender			
Male	361 (63.7%)	166 (66.4%)	195 (61.5%)
Female	206 (36.3%)	84 (33.6%)	122 (38.5%)
Side of hemiparesis			
Right	282 (49.7%)	124 (49.6%)	157 (49.5%)
Left	285 (50.35)	126 (50.4%)	160 (50.5)
Age(years)	60.9 (59.1–62.7)	63.4 (61.8–64.9)	59.0 (57.3–60.7)

Time since stroke(months)	15.3 (12.6–17.9)	1.3 (1.2–1.4)	26.3 (21.8–30.7)
Baseline FMA-UE(/66)	38.9 (37.5–40.3)	38.4 (36.3–40.5)	39.3 (37.5–41.1)
Baseline RPSS Close Target Score (/18)	12.5 (12.1–13)	14.1 (13.5– 4.7)	11.3 (10.7–11.9)
Baseline RPSS Far Target Score (/18)	11.8 (11.3–12.3)	13.4 (12.8–14)	10.6 (10–11.3)

CI: Confidence Interval; FMA-UE: Fugl-Meyer Assessment of the Upper Extremity; RPSS: Reaching Performance Scale for Stroke

Table 2: Correlation values based on orthogonal regressions between FMA-UE change scores and RPSS change scores to both targets

Stage of stroke		Data	RPSS Close Target change score	RPSS Far Target change score
Acute and Sub-acute	FMA-UE change score	All participants	0.690	0.686
		Those with change above	0.793	0.750

RPSS responsiveness

		MDC_{90}		
Chronic		All participants	0.639	0.659
		Those with change above MDC_{90}	0.652	0.637

FMA-UE: Fugl-Meyer Assessment of the Upper Extremity; RPSS: Reaching Performance Scale for Stroke