

Factors Associated with Clinical Meaningful Recovery after Upper Limb Task-Oriented Training in People with Stroke: A Cohort Study

NeuroRehabilitation
2025, Vol. 56(4) 469–479
© The Author(s) 2025
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/10538135251327090
journals.sagepub.com/home/nre



Alberto Romano¹ , Anna Di Meo¹ , Maurizio Ferrarin¹ , Rune Thorsen¹ ,
Davide Cattaneo² , Rita Bertoni¹ and Johanna Jonsdottir¹

Abstract

Background: Task-oriented training (TOT) is a commonly used intervention to improve upper extremity function after stroke. However, predictors of response to rehabilitation for performance and participation remain poorly understood.

Aim: To identify baseline predictors of clinically significant upper extremity (UE) recovery across impairment, performance, and participation in individuals post-stroke following TOT.

Methods: This is a retrospective study. Sixty-four individuals with stroke were enrolled and received five weeks of inpatient TOT for UE. Baseline characteristics and outcome measures were assessed using the Fugl-Meyer Assessment-Upper Extremity (FMA-UE) for impairment, the Action Research Arm Test (ARAT-15) for performance, and the QuickDASH-9 for participation. Participants were classified as responders and non-responders to the intervention, and binary logistic regression models were developed to predict responsiveness to impairment, performance, and participation measures.

Results: All outcome measures showed significant improvement post-intervention. The baseline FMA-UE score, chronicity, and dominance of the involved UE predicted responsiveness for impairment. The FMA-UE score was the main predictor of responsiveness in performance, while no predictors were identified for participation.

Conclusions: TOT improved UE impairment and performance in stroke patients, particularly those with moderate baseline impairment. Baseline UE function, chronicity, and dominance were key predictors of responsiveness in impairment and performance.

This study highlights the importance of personalized TOT after a stroke. It demonstrates that baseline function, chronicity, and affected limb dominance predict impairment and performance responsiveness to TOT while emphasizing the need to incorporate strategies that facilitate real-world skill transfer and address personal and environmental factors to maximize participation.

Keywords

stroke, task-Oriented training, upper extremity, rehabilitation, clinical decision rules, recovery of function

Received: 31 December 2024; accepted: 25 February 2025

Introduction

Stroke is the leading cause of disability in adults in Western countries, with an annual incidence in Europe of 191.9/100,000 cases per year (Soto et al., 2022). The literature reports that 35–40% of stroke survivors experience impairment of the upper extremities (UE) (Dalton et al., 2024), causing performance and participation restrictions (Faria-Fortini et al., 2011). Limitations in reaching and grasping play a crucial

¹IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy

²Department of Pathophysiology and Transplantation, Università degli Studi di Milano, Milan, Italy

Corresponding Author:

Rita Bertoni, LaRiCE Research Unit, IRCCS Fondazione Don Carlo Gnocchi, Via Alfonso Capecelatro, 66, 20148 Milano MI, Italy.
Email: rbertoni@dongnocchi.it

role in determining a person's independence in daily activities and their subsequent impact on quality of life (Anwer et al., 2022). Overcoming such limitations represents one of the principal goals of rehabilitation interventions. Various rehabilitation approaches have been proposed to promote UE functioning recovery after stroke, including constraint-induced movement therapy (CIMT) (de Azevedo et al., 2022), action-observation (Borges et al., 2022), task-oriented training (TOT) (Hussain et al., 2022), and TOT combined with functional electrical stimulation (FES) (Jonsdottir et al., 2017).

TOT is a therapeutic approach grounded in the principles of motor learning and neural plasticity, commonly used in stroke rehabilitation to enhance motor skills and daily activity performance (Favetta et al., 2023). TOT tasks for UE motor rehabilitation after stroke endorse the massive active practice of finalized activities like reaching and grasping to promote brain reorganization, maximize functional performance, and restore UE function. TOT has been reported as effective in promoting UE strength and functional recovery (Hussain et al., 2022) with at least comparable effects to usual care (Alashram et al., 2019), while little is known about TOT's impact on the participation component.

Since many interacting factors may affect stroke rehabilitation outcomes, the American Stroke Association recommends developing predictor models for identifying responders and non-responders at the impairment, performance, and participation levels (Winstein et al., 2016). Thakkar et al. (2020) studied the predictors of significant UE function recovery as assessed with the Fugl-Meyer assessment (FMA) after 30 h of TOT in 239 patients with stroke. The authors identified the time since the stroke, the initial functional ability of the participants (evaluated with the Functional Independence Measures), and the baseline residual motor function of the paretic arm assessed through the FMA. However, while the FMA has been related to the impairment (Schiefelbein et al., 2019), the baseline patients' characteristics associated with responsiveness to UE TOT at the performance and participation level remain less studied. Identifying predictors for performance and participation may help tailor treatment plans and more accurately stratify patients toward a better overall outcome.

The current retrospective analysis evaluates the predictors associated with significant response to rehabilitation measured with outcome measures of impairment, performance, and participation restrictions. Candidate predictors were identified from the relevant literature and include: a) age, b) sex, c) dominance of affected body side, d) the time since stroke, e) the injury typology (ischemic; hemorrhagic), and f) localization (cortical; sub-cortical), and the baseline scores of g) impairment (Fugl-Meyer Upper Extremity Assessment - FMA-UE), h) performance (15-item Action Research Arm Test - ARAT-15), and i) participation (Quick version of the Disability of the Arm, Shoulder, and Hand questionnaire - 9 items - Q-DASH-9).

Materials and Methods

For the current study, a retrospective analysis was conducted on data collected on UE rehabilitation for post-acute people with stroke conducted at the IRCCS Fondazione Don Carlo Gnocchi (Milan, Italy) between 2011 and 2015. The study was conducted following the Declaration of Helsinki. All participants provided written informed consent for data publication before data collection.

Participants were required to be at least one-month post-stroke and participate fully in the study. Minimum criteria included voluntary activation of shoulder flexor activation and a passive range of motion exceeding 90° in the shoulder and elbow, with no severe upper limb spasticity, and having a MiniMental State Examination higher than 23, as a score of <24 is the generally an accepted cutoff indicating the presence of cognitive impairment (Dick et al., 1984). Exclusion criteria were the presence of epilepsy, respiratory insufficiency, pregnancy, and peripheral neuropathies. All participants received a TOT applied following the components reported by Timmermans et al. (2010). TOT involved practicing functional tasks directed towards a clear functional goal to acquire or reacquire specific skills. The intervention was progressively adapted to the patient, encompassing reaching for and manipulating real-life objects. The intervention protocol comprised 25 sessions, each lasting 45 min, conducted five days a week throughout five to six weeks.

Data Collection and Outcome Measures

The enrolled participants were assessed before (pre-intervention) and after (post-intervention) five to six weeks of UE rehabilitation by the same physical therapist experienced in the functional evaluation of people with stroke. Candidate predictors for the current analysis included anamnestic information and outcome measures assessed pre-intervention. Specifically, participants' anamnestic information comprised age (years), sex (male; female), dominance of affected body side (dominant; non-dominant), the time between the stroke and the evaluation (months), and the injury typology (ischemic; hemorrhagic) and localization (cortical; sub-cortical). The participants' lesions were categorized as sub-acute if the stroke occurred between one and six months before the first evaluation and as chronic if the accident happened more than six months before the pre-intervention assessment. The outcome measures were selected to assess UE impairment and performance, as well as participation restriction.

The Fugl-Meyer Assessment – Upper Extremity. The FMA-UE (Fugl-Meyer et al., 2011) is a widely used evaluation tool for measuring upper limb impairment following a stroke. The scale measures the impairment of proximal and distal synergic and isolated voluntary movements. It includes

four sub-sections: i) shoulder-arm, ii) wrist, iii) hand, and iv) coordination and speed. The FMA-UE comprises 33 items, from the most to the least complex. Each item is scored on a 3-point ordinal scale with a maximum score of 66 points. A higher score indicates higher upper extremity functionality. The FMA-UE was used to assess impairment (Schiefelbein et al., 2019). It has shown high interrater and test-retest reliability (Lin et al., 2009).

The 15-item Action Research Arm Test (ARAT-15). The ARAT assesses the proximal and distal UE function, performance, and dexterity. It is commonly used to evaluate the effectiveness of changes in the UE performance following stroke rehabilitation treatment (Murphy et al., 2015). Mokken analysis was used to investigate the dimensionality of the ARAT, identifying a subset of 15 items that showed invariant hierarchical items' ordering and responsiveness ratio (van der Lee et al., 2002) compared with the 19-item original ARAT (Lyle, 1981). Each item is scored on a discrete scale ranging from 0 (indicating no movements) to 3 (representing normal movement). The ARAT-15 allows a maximum score of 45 points, with a higher score indicating better upper extremity functionality.

The Quick Version of the Disability of the Arm, Shoulder, and Hand Questionnaire - 9 Items (Q-DASH-9). The Disabilities of the Arm, Shoulder, and Hand (DASH) (Hudak et al., 1996) is a 30-item self-report questionnaire that inquires on the use of the UE in the daily life of the last week. The Q-DASH-9 is a unidimensional measure consisting of 9 items scored on a 0–4 Likert scale, utilizes the DASH scoring method, and allows for one missing response. The scale provides a normalized total score ranging from 0% to 100%, whereas a lower score corresponds to milder disability. It showed a high test-retest reliability coefficient, internal consistency, and responsiveness (Gabel et al., 2009). The Q-DASH-9 was selected as a measure of participation limitation (Metcalf et al., 2007).

Data Analysis

The statistical analysis was conducted using the RStudio software (version 2023.12.0 + 369 "Ocean Storm" release). The data were presented using descriptive statistics. Categorical variables were described using counts and percentages, while quantitative variables were described using the median and range. The Shapiro-Wilk test assessed the normality of quantitative variable distributions.

Wilcoxon signed-rank test compared outcome measures at before and after TOT. Effect sizes (ES) were calculated using matched-pairs rank-biserial correlation (King et al., 2018; Tomczak & Tomczak, 2014). ES was considered small (0.1–0.3), medium (0.3–0.6), or large (>0.6) following previous recommendations (Kinney et al., 2020).

Participants were divided into Responders and Non-responders for each outcome measure (FMA-UE, ARAT-15, and Q-DASH-9). Responders showed a change (pre- vs. post-treatment) exceeding the minimally clinically important difference (MCID): five points for FMA-UE (Page et al., 2012) and ARAT-15 and 10 points for Q-DASH-9 (Van der Lee et al., 2001). Participants were excluded if their baseline scores were too high to demonstrate the MCID, at least in one outcome measure.

A stepwise binary logistic regression model was developed to anticipate whether participants would be Responders or Non-responders based on T0 characteristics. The Akaike information criterion (AIC) guided variable selection, balancing model fit and complexity. A bidirectional (forward and backward) approach was used, adding/removing predictors based on AIC improvement.

Due to the high correlation with other baseline scores (ARAT-15 and Q-DASH-9), only the FMA-UE baseline score was included in the stepwise analysis, reducing the number of candidate predictors to seven. If all seven candidate predictors were included in the model, a sample size of 75 was required based on a statistical power of 80%, a significance level of 5%, and an ES of 0.4.

The data scatterplots were visually analyzed to identify meaningful relation patterns and interactions between outcome measures' deltas and candidate predictor variables that may be missed using the stepwise analysis (Moore et al., 2015). If a relation pattern was observable in the scatterplots, it was added as a predictor to the model identified by the stepwise analysis to evaluate its potential improvement. If the model alignment with the original data improved, the newly added variable was kept. Otherwise, it was removed from the model.

McFadden's index of explained variance (pseudo-R²) and the Scaled Brier Score (sBS) were calculated to measure the proportion of explained variance and assess the overall prediction accuracy, respectively (Hair et al., 2019; Steyerberg et al., 2010). Moreover, the Receiver Operating Characteristic curve was constructed, and the Area Under the Curve (AUC) was evaluated to summarize the model's discriminatory power (Hair et al., 2019). Finally, the Hosmer–Lemeshow test assessed the fit between expected and estimated frequencies (Hosmer et al., 2013). The regression model was considered aligned with the original data under specific conditions: (i) The closer the pseudo-R² is to 1, the more satisfactory the model is; (ii) The closer the sBS is to 0, the more informative the model is; (iii) AUC values > 0.70 indicate a moderately accurate model; (iv) a non-significant Hosmer–Lemeshow value (> 0.05) suggests acceptable model fit.

Furthermore, the identified predictors of each model were evaluated by analyzing their estimated coefficient values (slopes), standard errors, z-value, and odds ratio. Bonferroni correction for multiple comparisons was applied to the significance threshold for the z-values' p-values, which was therefore set for each model at $\alpha < (0.05 / \text{model's predictors number})$.

Table 1. Descriptive Statistics of Collected Quantitative Variables and Results of Comparisons Between Outcome Measures Collected at T0 and T1.

	Media (SD)	Median (Range)	T0 vs T1 P-value (ES)
Age at T0 (years)	65.3 (15.0)	68.2 (25.0–88.7)	/
Time from stroke (months)	15.4 (32.9)	3.5 (0.8–190.1)	/
FMA-UE at T0	28.4 (17.8)	28.5 (2.0–61.0)	<0.001*
FMA-UE at T1	35.7 (17.8)	39.0 (5.0–66.0)	(0.946)
ARAT-15 at T0	14.7 (14.9)	11.0 (0.0–46.0)	<0.001*
ARAT-15 at T1	21.3 (16.9)	22.0 (0.0–51.0)	(0.968)
Q-DASH-9 at T0	55.2 (18.1)	59.1 (14.0–84.1)	<0.001*
Q-DASH-9 at T1	49.0 (19.7)	54.3 (7.0–79.8)	(0.647)

*: p-value < 0.05.

/: no data for the cell.

Abbreviation list: SD = Standard Deviation; ES = Effect size; FMA-UE = Fugl-Meyer Assessment – Upper Extremity; ARAT-15 = 15-item Action Research Arm Test; Q-DASH-9 = Quick version of the Disability of the Arm, Shoulder, and Hand questionnaire – 9 items.

Finally, a subgroup sensitivity analysis (Thabane et al., 2013) was conducted to assess how changes in the input variables or model assumptions affect the models' output. The dataset was divided into subgroups based on the dichotomous variables not included in the evaluated model. Then, the model was tested on the obtained subgroups, and the directions (sign) of the predictors' estimated coefficients were compared with those obtained with the entire dataset. Model sensitivity was considered confirmed if the direction of the predictors' estimated coefficients remained stable in all the sensitivity analysis conditions.

Results

Sixty-four individuals were included in the prediction models. No participants have missing data for any predictor variable. Table 1 presents descriptive statistics of quantitative variables and results of comparisons between outcome measures collected before and after TOT. Statistically significant improvement with large ESs was achieved in all outcome measure scores. The average change in the FMA-UE and ARAT-15 exceeded the scales' MCID (Table 2). At the FMA-UE, 35 subjects (54.7%) were classified as "Responders," at the ARAT-15, 32 (50.0%), and at the Q-DASH-9, 23 (35.9%).

Binary Logistic Regression Models

The stepwise analysis identified predictors for each logistic regression model. Table 2 presents the delta of each outcome measure in each subgroup obtained by dividing the sample based on the collected categorical variable before and after TOT.

Scatterplot visual inspection has suggested exploring the square FMA-UE as candidate predictors to be added to the

FMA-UE and ARAT-15 models. Since the model fit improved, it was kept as a predictor variable. Table 3 summarizes the evaluation of the models' fitting of the original data, along with the estimated coefficients of related predictors.

FMA-UE Model. The model to anticipate the responsiveness to TOT at the FMA-UE (impairment) showed an overall accuracy of 73.4% (specificity = 69.0%; sensitivity = 77.1) and explained 25.4% of the variance. Subjects with sub-acute stroke were 6.4 times more likely to be Responders compared to subjects with chronic stroke. Subjects with a dominant UE affected were 8.6 times more likely to be Responders than subjects with their non-dominant limb affected. Moreover, the baseline FMA-UE score showed an inverted U-shaped relation to the probability of being a Responder to the treatment. The highest probability of being a Responder was found when the FMA-UE score at T0 was around 32.7. Figure 1 presents the probability of being a Responder at the FMA-UE at T1, calculated by the model as the predictor variables change.

ARAT-15 Model. The model to anticipate the responsiveness to TOT at the ARAT-15 (performance) showed a general accuracy of 78.1% (specificity = 75.0%; sensitivity = 81.3%) and explained 37.4% of the variance. The variables "Sex" and "Chronicity" were found to reduce the model's AIC and improve the model's explained variance, accuracy, and AUC. However, they do not seem to provide significant information on the subjects' potential for recovery. Male subjects showed 3.5 times the probability of being responders than females. Subjects categorized as sub-acute had about 4.7 times the likelihood of responding positively to the treatment compared to those with chronic lesions. These probabilities did not reach statistical significance due to the wide standard errors in the estimated values. Finally, the FMA-UE score at T0 showed an inverted-U shape relation with the probability of being a Responder to the treatment. The greatest likelihood of being a Responder was identified when the FMA-UE score at T0 was 38.2. The variation in the probability of being a Responder at the ARAT-15 at T1, as determined by the model in response to changes in the incorporated variables, is depicted in Figure 2.

Q-DASH-9 Model. The model identified by the stepwise analysis for anticipating the responsiveness to TOT at the Q-DASH-9 (participation) approached without reaching the statistical significance. The model accuracy was 70.3% (specificity = 90.2%; sensitivity = 34.8%), and the AUC indicates a moderately accurate model. However, the model explains only 8.7% of the distribution variance, and none of the predictors improved the fit of the data compared to a model without predictors.

Table 2. Descriptive Statistics of Changes in the Participants' Outcome Measure Scores (Deltas – Δ) Divided into Subgroups Based on Collected Categorical Variables.

Variable	Subgroup no. (%)	Δ FMA-UE		Δ ARAT-15		Δ Q-DASH-9	
		Median (IQR)	% Resp/% Non-Resp	Median (IQR)	% Resp/% Non-Resp	Median (IQR)	% Resp/% Non-Resp
Sex	Males 27 (42.2%)	5.0 (13.5)	51.9 / 48.1%	7.0 (7.5)	59.3 / 40.7%	-2.3 (11.3)	25.9 / 74.1%
	Females 37 (57.8%)	5.0 (8.0)	56.8 / 43.2%	2.0 (13.0)	43.2 / 56.8%	-6.8 (12.6)	43.2 / 56.8%
Injury typology	Ischemic 50 (78.1%)	5.0 (12.0)	56.0 / 44.0%	4.5 (11.0)	50.0 / 50.0%	-4.8 (13.4)	38.0 / 62.0%
	Hemorrhagic 14 (21.9%)	5.5 (7.2)	50.0 / 50.0%	6.5 (8.0)	50.0 / 50.0%	-2.0 (9.5)	28.6 / 71.4%
Chronicity	Chronic 24 (37.5%)	3.5 (6.2)	37.5 / 62.5%	2.0 (9.0)	41.7 / 58.3%	-4.5 (11.6)	33.3 / 66.7%
	Subacute 40 (62.5%)	6.5 (11.0)	65.0 / 35.0%	7.0 (13.0)	55.0 / 45.0%	-4.8 (13.6)	37.5 / 62.5%
Injury Localization	Subcortical 22 (34.4%)	7.5 (14.3)	63.6 / 36.4%	6.5 (11.8)	59.1 / 40.9%	-5.9 (15.4)	45.5 / 54.5%
	Cortical 42 (65.6%)	4.5 (6.5)	50.0 / 50.0%	2.5 (9.7)	45.2 / 54.8%	-3.4 (11.2)	30.9 / 69.1%
Dominance of affected bodyside	Non-Dominant 32 (50.0%)	4.0 (7.2)	40.6 / 59.4%	8.0 (11.0)	53.1 / 46.9%	-3.4 (11.1)	28.1 / 71.9%
	Dominant 32 (50.0%)	6.0 (11.3)	68.7 / 31.3%	3.5 (10.0)	46.9 / 53.1%	-5.9 (13.0)	43.7 / 56.3%
Total 64 (100%)		5.0 (11.3)	54.7 / 45.3%	4.5 (11.0)	50.0 / 50.0%	-4.5 (13.6)	35.9 / 64.1%

Abbreviation list: FMA-UE = Fugl-Meyer Assessment – Upper Extremity; ARAT-15 = 15-item Action Research Arm Test; Q-DASH-9 = Quick version of the Disability of the Arm, Shoulder, and Hand questionnaire – 9 items; IQR = Inter Quartile Range; Resp = Responders; Non-Resp = Non-Responders.

Sensitivity Analysis

The robustness of the developed models was evaluated with subgroups created by dividing the initial sample based on variables not included in the model. Detailed sensitivity analysis results are available in Supplemental Material 1 (<https://doi.org/10.6084/m9.figshare.27222834.v3>).

The directions shown by the estimated coefficients of the predictors included in the models to anticipate the significant change at the FMA-UE, and ARAT-15 did not change in any conducted analysis. Conversely, the direction of the estimated coefficients of predictors identified to anticipate a significant change in the Q-DASH-9 changed in all the subgroup analyses.

Discussion

To the authors' knowledge, this study is the first attempt to explore predictors associated with responsiveness to TOT applied to UE rehabilitation for people post-stroke at impairment, performance, and participation levels. Significant recovery was recorded with all the investigated outcome measures at the post-intervention evaluation with a large ES, particularly on FMA-UE and ARAT, where average score changes exceeded MCIDs, supporting the potential of such rehabilitative interventions in promoting UE functioning (Lee & Howe, 2024). However, clinically significant recovery in the participation component assessed using the Q-DASH-9 was seen only in a minority of subjects (35.9%), suggesting TOT impacted the impairment and performance more. Consistently, previous studies on TOT and CIMT emphasized the importance of integrating

elements aimed at translating the practice done in the clinic to the daily living environment by experiencing arm and hand use in tasks and roles meaningful for the participant (Lewthwaite et al., 2018). Moreover, individual variability in response underlines the need to explore all predictors associated with functional recovery to better support intervention tailoring.

The stepwise analysis identified predictors related to responsiveness to TOT. Concerning the impairment assessed with the FMA-UE, the identified model had high discriminatory power, explaining 25.4% of the variance with chronicity, arm affected, and FMA baseline score as best predictors. Participants with sub-acute lesions showed a fivefold greater potential to be Responders than those with chronic injuries, also accounting for spontaneous recovery after stroke, which occurs in the first six months after the lesion (Grefkes et al., 2020). Although the probability of being a Responder is lower for people with chronic stroke, the literature highlights that training may bring functional recovery even in the chronic stroke phase (Cramer, 2008). Furthermore, when the non-dominant limb was affected, the probability of being a Responder was dramatically reduced (see Figure 1) compared to when the stroke affected the dominant limb (Lima et al., 2014). This may be due to motivational issues. If the dominant hand is affected, individuals may be more motivated to use it during recovery because they are not familiar with using their non-dominant hand for daily tasks (Harris & Eng, 2006). Therefore, providing the patient with opportunities to integrate the affected arm into daily activities during TOT is even more crucial for people with non-dominant paresis to achieve functional recovery. The pre-

Table 3. Summary of the Conducted Regression Models and Evaluation of Coefficients of Related Predictors.

Dependent variable (model's accuracy; p-value)					
FMA-UE (0.734; < 0.001*)	Model's fitting indexes	R²_{McF}	sBS	pH-L	AUC
		0.254	0.170	0.382	0.830
	Predictors' coefficients	Predictor	β ± SE	Z-value (p-value)	Odds-Ratio (95% CI)
		Intercept	-4.9 ± 1.4	-3.4 (<0.001 [§])	<0.1 (<0.1–0.1)
		Chronicity	1.9 ± 0.7	2.6 (0.008 [§])	6.4 (1.6–25.5)
		Dominance of affected bodyside	2.2 ± 0.7	2.9 (0.003 [§])	8.6 (2.0–36.3)
ARAT-15 (0.781; <0.001*)	Model's fitting indexes	R²_{McF}	sBS	pH-L	AUC
		0.374	0.145	0.740	0.886
	Predictors' coefficients	Predictor	β ± SE	Z-value (p-value)	Odds-Ratio (95% CI)
		Intercept	-6.9 ± 1.6	-3.9 (<0.001 [§])	<0.1 (<0.1 – <0.1)
		Sex	1.3 ± 0.7	1.7 (0.088)	3.5 (0.8–14.9)
		Chronicity	1.6 ± 0.8	2.0 (0.042)	4.7 (1.1–20.8)
Q-DASH-9 (0.703; 0.065)	Model's fitting indexes	R²_{McF}	sBS	pH-L	AUC
		0.087	0.203	0.757	0.717
	Predictors' coefficients	Predictor	β ± SE	Z-value (p-value)	Odds-Ratio (95% CI)
		Intercept	1.6 ± 1.2	1.3 (0.190)	5.0 (0.4–56.5)
		Sex	-0.9 ± 0.6	-1.5 (0.141)	0.4 (0.1–1.3)
		Injury Localization	0.9 ± 0.6	-1.5 (0.137)	2.4 (0.8–7.5)
	Predictors' coefficients	Predictor	β ± SE	Z-value (p-value)	Odds-Ratio (95% CI)
		Age at T0	-0.03 ± 0.02	-1.8 (0.074)	1.0 (0.9–1.0)

*: p < 0.050.

§: p < (0.050/model's predictors number).

The reference levels selected for each outcome measure and categorical predictor are the following (Outcome/Predictor variable – Reference level): FMA-UE – Non-responders; ARAT-15 – Non-responders; Q-DASH-9 – Non-responders; Sex – Female; Chronicity – Chronic; Dominance of affected bodyside – Non-Dominant; Injury localization – Cortical.

Abbreviation list: R²_{McF} = McFadden's pseudo-R²; sBS = Scaled Brier Score; pH-L = Hosmer-Lemeshow test's p-value; AUC = Area Under the Curve; β ± SE = Estimate of regression coefficient with Standard Error; CI = Confidence Interval; FMA-UE = Fugl-Meyer Upper Extremity Assessment; ARAT-15 = 15-item Action Research Arms Test; Q-DASH-9 = Quick version of the Disability of the Arm, Shoulder, and Hand questionnaire – 9 items.

intervention level of UE functionality was a critical determinant of the potential for recovery after the intervention, echoing the existing literature (Corrado et al., 2015; Park & Kim, 2023). The current findings highlight a significantly broader probability of being a Responder when the patient presents a moderate UE impairment, which aligns with the existing literature (Coupar et al., 2012). Due to insufficient residual movement to actively perform a motor task, people with severe UE impairment were historically excluded from TOT (Barker & Brauer, 2005). Stroke survivors with a severe impairment may benefit more from TOT when it is applied in association with other techniques (e.g., robot-assisted rehabilitation) (Perini et al., 2021). When such combined treatments are not feasible, intervention for severely affected UE should focus on maintaining arm mobility and tissue elasticity, combined with compensatory training of the non-affected arm to maximize activity

performance, participation, and independence (Anwer et al., 2022). Moreover, because only four patients had a mild impairment (as defined by Woytowicz et al. (2017)), no reliable conclusions can be drawn about the likelihood of these subjects being Responders.

Regarding responsiveness at the performance level assessed with the ARAT-15, the model presented high discriminatory power, explaining about 37% of the variance. The baseline FMA-UE score was the most influential predictor for anticipating significant recovery, which aligns with the existing literature (Coupar et al., 2012). In the current sample, people with moderate impairment showed the highest potential of recovering their performance. Performance tasks require good UE functioning and personal satisfaction with activities has been reported as being related to upper-limb functioning (along with individual and environmental factors) (Coupar et al., 2012). These elements suggest that similar treatments to the proposed

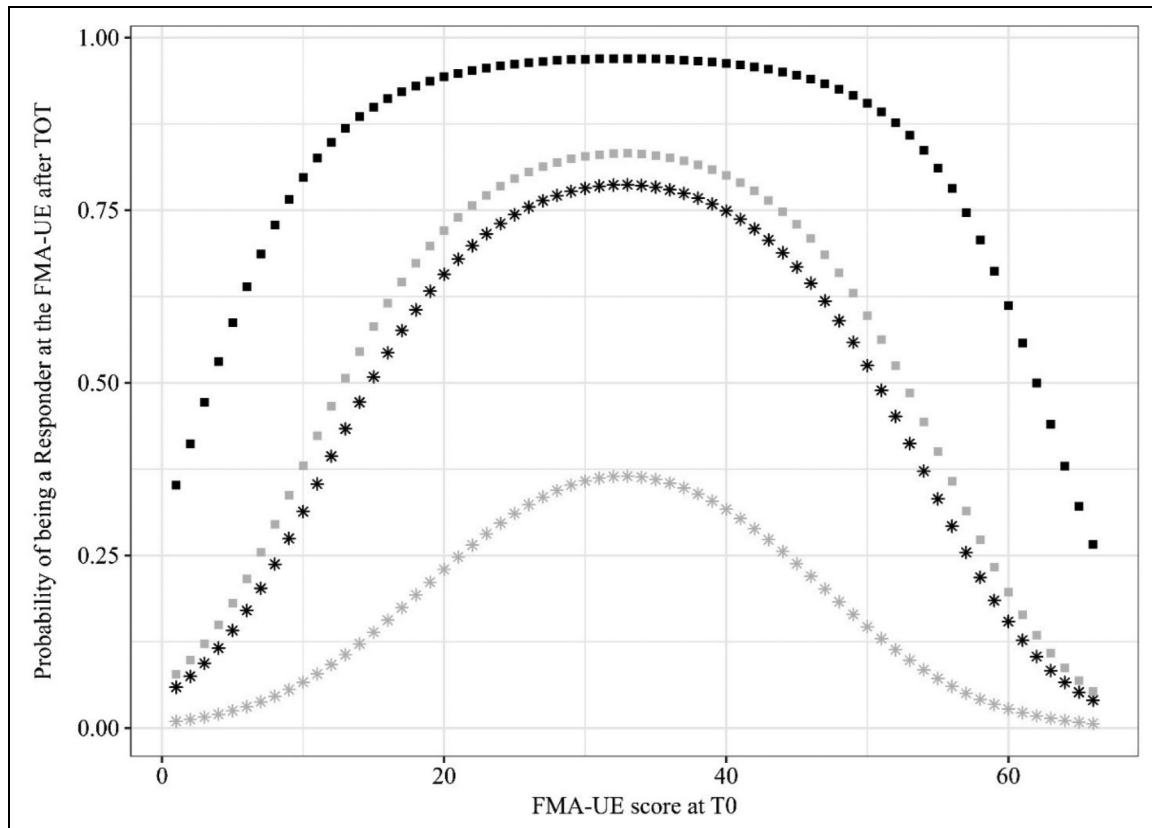


Figure 1. Probability of being responders to the FMA-UE at T1 as calculated by the model when the included variables change. The black curves refer to sub-acute lesions, and the grey ones to chronic lesions. Squares indicate a dominant UE affected and asterisk a non-dominant limb affected.

intervention may not enhance the patient's UE performance when the baseline impairment of UE is severe. In such cases, recovering the performance level of the affected arm may require preliminary interventions to ameliorate the UE impairment (Kwakkel & Kollen, 2015). Furthermore, sex emerged as a predictor that enhances the model's accuracy without significantly informing on the person's responsiveness potential. The literature reports that males appear to achieve better recovery, although conflicting findings were reported concerning sex differences in rehabilitation efficacy (Coupar et al., 2012). It has to be considered that sex relevance may hide other biological, social, or psychological differences between men and women accounting for different activity outcomes (Carcel et al., 2020). Finally, the "chronicity" variable enhances the model's accuracy but is not informative on the person's potential of being a Responder when kept alone. This suggests that chronicity status was not highly relevant when considering implementing TOT-based intervention to enhance performance. Post-intervention responsiveness in performance seems more linked to the underlying impairment, which is highly impacted by the spontaneous recovery occurring in the first six months after stroke (Kwakkel & Kollen, 2013).

None of the candidate predictors was informative on the participants' responsiveness potential in the

participation measured with the Q-DASH-9, leading to a non-significant model. The potential for participation recovery may be linked to factors not included in the current retrospective analysis. Participation is the combined consequence of a person's impairments, performance limitations, and personal and environmental factors. These factors are frequently independent of clinical variables and may promote or restrain participation (Della Vecchia et al., 2023). The anticipatory potential of these factors for participation responsiveness is still to be explored. Coherently, age and sex variables were selected as predictors by the stepwise analysis. These variables are linked to personal and social characteristics, such as additional disabilities or comorbidities and level of assistance (Phan et al., 2018), which may be important for participation recovery.

We recognize three limitations of this study. First, retrospective design limited the available candidate predictors to be included in the models. This and the absence of a control group did not allow exploring cause-effect solid relationships. Second, the small sample size challenges the findings' external validity. However, although 75 subjects were required if seven candidate predictors were included in the models, no more than four predictors were included in

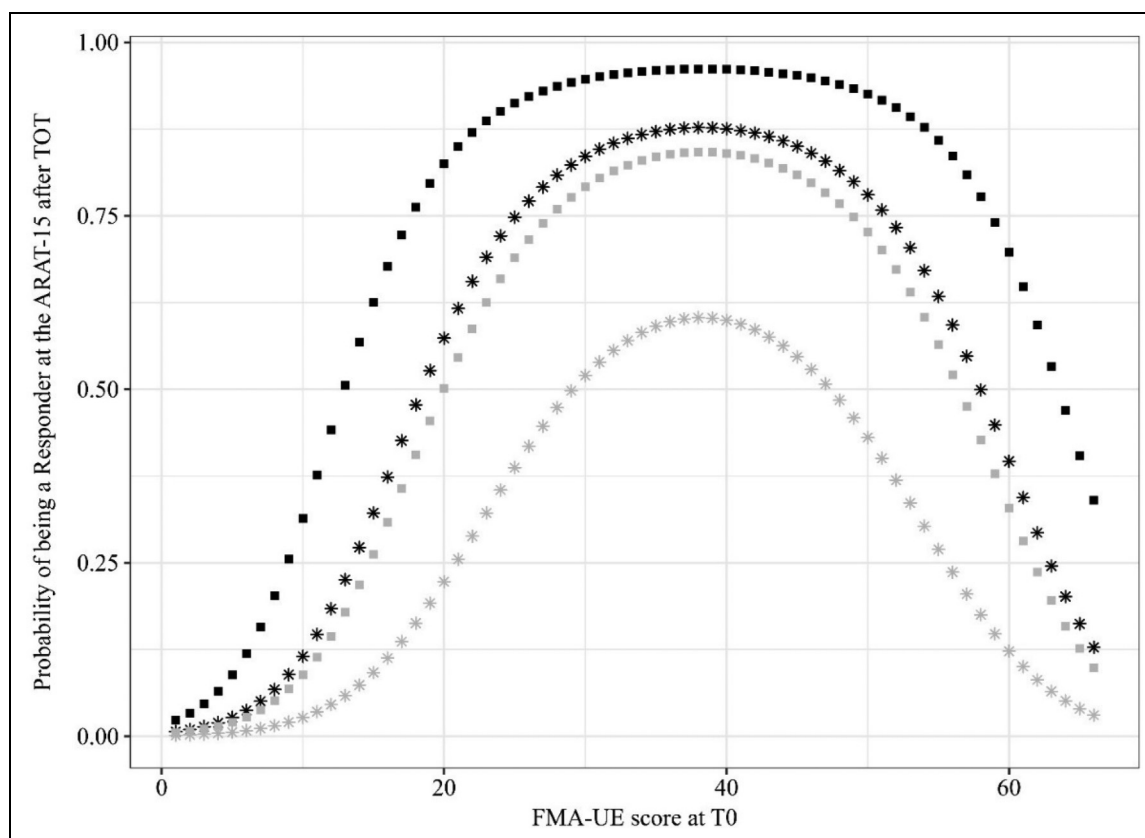


Figure 2. Probability of being responders to the ARAT-15 at T1 as calculated by the model when the included variables change. The black curves refer to sub-acute lesions, and the grey ones to chronic lesions. Squares indicate male and asterisk female subjects.

each model. A model with four predictors requires a sample size of 63 subjects based on a statistical power of 80%, a significance level of 5%, and an ES of 0.4, which was reached in the current study. Furthermore, only four subjects presented an FMA-UE at T0 above 53, reported as a cut-off score for a mild UE impairment in people with stroke (Woytowicz et al., 2017). This limits the validity of inferences related to this group of stroke survivors. Third, the considered outcome measures' MCID was the same for participants with chronic and sub-acute lesions, leading to possible overestimation of the "Chronicity" variable.

Conclusion

The UE impairment and performance significantly recovered at the post-intervention evaluation, but the effect on participation was less pronounced. The study's findings highlight the importance of baseline UE function, chronicity, and dominance of involved UE as critical predictors for a response to TOT at the impairment and performance levels. However, no predictors of responsiveness at the participation level were identified, suggesting the need for further exploration of personal and environmental factors. Results indicate that individuals with moderate-mild to moderate-severe UE

impairments were more likely to respond to the treatment than those severely affected. These findings underscore the importance of tailored interventions to interindividual needs and functional levels, emphasizing the importance of a comprehensive approach incorporating physical, personal, and environmental factors to promote positive outcomes after stroke rehabilitation. This study provides further evidence supporting the effectiveness of TOT in post-stroke UE rehabilitation. It gives valuable insights for clinicians to implement personalized treatment plans based on individual characteristics and needs. Future research should focus on identifying additional predictors linked to participation recovery and exploring the long-term effects of TOT-based interventions on UE impairment, performance, and participation.

Acknowledgments

The authors acknowledge Mr. Alessandro Torchio from IRCCS Fondazione Don Gnocchi for his significant contribution to the statistical analysis.

ORCID iDs

Alberto Romano  <https://orcid.org/0000-0001-9774-2964>

Anna Di Meo  <https://orcid.org/0009-0007-6389-7379>

Maurizio Ferrarin  <https://orcid.org/0000-0002-7797-2399>
 Rune Thorsen  <https://orcid.org/0000-0003-1990-8839>
 Rita Bertoni  <https://orcid.org/0000-0001-9533-5716>
 Johanna Jonsdottir  <https://orcid.org/0000-0002-8287-4881>

Statements and Declarations

Author Contributions

Conceptualization: Rita Bertoni and Johanna Jonsdottir; Data Curation: Alberto Romano, Anna Di Meo, Davide Cattaneo, Rita Bertoni, and Johanna Jonsdottir; Formal Analysis: Alberto Romano, Anna Di Meo, and Davide Cattaneo; Funding Acquisition: Maurizio Ferrarin and Johanna Jonsdottir; Investigation: Alberto Romano, Anna Di Meo, Rune Thorsen, Rita Bertoni, and Johanna Jonsdottir; Methodology: Alberto Romano, Rune Thorsen, Davide Cattaneo, Rita Bertoni, and Johanna Jonsdottir; Project Administration: Maurizio Ferrarin and Johanna Jonsdottir; Resources: Maurizio Ferrarin, Rune Thorsen, Davide Cattaneo, and Johanna Jonsdottir; Supervision: Maurizio Ferrarin, Rune Thorsen, Davide Cattaneo, and Johanna Jonsdottir; Validation: Maurizio Ferrarin, Rune Thorsen, Davide Cattaneo, Rita Bertoni and Johanna Jonsdottir; Writing – Original Draft: Alberto Romano and Anna Di Meo; Writing – Review & Editing: Maurizio Ferrarin, Rune Thorsen, Davide Cattaneo, Rita Bertoni, and Johanna Jonsdottir. All authors read and approved the final version of the manuscript.

Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki. Ethical Committee approval was waived for the current study as it is a retrospective analysis of data collected within the clinical activity.

Informed consent

All participants provided written informed consent for data publication before data collection.

Funding

AR was supported by the European Union – NextGenerationEU (PNRR M4C2 – Investimento 1.5 Dalla ricerca all'impresa), under Grant ECS_00000035 (project “RAISE-Robotics and AI for Socio-economic Empowerment”). ADM was supported by the European Union – NextGenerationEU (PNRR M6C2 – Investimento 2.1 Valorizzazione e potenziamento della ricerca biomedical del SSN) under Grant PNRR-POC-2022-12375689 (project “PoCH-Rehab”).

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability

The data presented in this paper are openly available in the figshare repository at <https://doi.org/10.6084/m9.figshare.27222687>.

References

- Alashram, A. R., Annino, G., & Mercuri, N. B. (2019). Task-oriented motor learning in upper extremity rehabilitation post stroke. *Journal of Stroke Medicine*, 2(2), 95–104. <https://doi.org/10.1177/2516608519864760>
- Anwer, S., Waris, A., Gilani, S. O., Iqbal, J., Shaikh, N., Pujari, A. N., & Niazi, I. K. (2022). Rehabilitation of upper limb motor impairment in stroke: A narrative review on the prevalence, risk factors, and economic statistics of stroke and state of the art therapies. *Healthcare (Switzerland)*, 10(2), 190. <https://doi.org/10.3390/healthcare10020190>
- Barker, R. N., & Brauer, S. G. (2005). Upper limb recovery after stroke: The stroke survivors' perspective. *Disability and Rehabilitation*, 27(20), 1213–1223. <https://doi.org/10.1080/09638280500075717>
- Borges, L. R. D. M., Fernandes, A. B. G. S., Oliveira dos Passos, J., Rego, I. A. O., & Campos, T. F. (2022). Action observation for upper limb rehabilitation after stroke. *Cochrane Database of Systematic Reviews*, 2022(8), CD011887. <https://doi.org/10.1002/14651858.CD011887.pub3>
- Carcel, C., Woodward, M., Wang, X., Bushnell, C., & Sandset, E. C. (2020). Sex matters in stroke: A review of recent evidence on the differences between women and men. *Frontiers in Neuroendocrinology*, 59, 100870. <https://doi.org/10.1016/j.yfrne.2020.100870>
- Corrado, B., Macca, M., Ciardi, G., Serevodio Iammarone, C., & Schiro, G. (2015). Functional short-term recovery factors in patients with stroke: A retrospective observational cohort study. *International Journal of Physiotherapy*, 2(6), 1027–1034. <https://doi.org/10.15621/ijphy/2015/v2i6/80764>
- Coupar, F., Pollock, A., Rowe, P., Weir, C., & Langhorne, P. (2012). Predictors of upper limb recovery after stroke: A systematic review and meta-analysis. *Clinical Rehabilitation*, 26(4), 291–313. <https://doi.org/10.1177/0269215511420305>
- Cramer, S. C. (2008). Repairing the human brain after stroke: I. Mechanisms of spontaneous recovery. *Annals of Neurology*, 63(3), 272–287. <https://doi.org/10.1002/ana.21393>
- Dalton, E. J., Jamwal, R., Augoustakis, L., Hill, E., Johns, H., Thijs, V., & Hayward, K. S. (2024). Prevalence of arm weakness, pre-stroke outcomes and other post-stroke impairments using routinely collected clinical data on an acute stroke unit. *Neurorehabilitation and Neural Repair*, 38(2), 148–160. <https://doi.org/10.1177/15459683241229676>
- de Azevedo, J. A., Barbosa, F. D. S., Seixas, V. M., da Silva Scipioni, K. R. D., Sampaio, P. Y. S., da Cruz, D. M. C., Piscitelli, D., Chui, K. K., & de Freitas Zanona, A. (2022). Effects of constraint-induced movement therapy on activity and participation after a stroke: Systematic review and meta-analysis. *Frontiers in Human Neuroscience*, 16, 987061. <https://doi.org/10.3389/fnhum.2022.987061>
- Della Vecchia, C., Préau, M., Haesebaert, J., Viprey, M., Rode, G., Termoz, A., Dima, A., & Schott, A. M. (2023). Factors associated with post-stroke social participation: A quantitative study based on the ICF framework. *Annals of Physical and Rehabilitation Medicine*, 66(3), 101686. <https://doi.org/10.1016/j.rehab.2022.101686>
- Dick, J. P. R., Guilloff, R. J., & Stewart, A. (1984). Mini-mental state examination in neurological patients. *Journal of*

- Neurology, Neurosurgery & Psychiatry*, 47(5), 496–499. <https://doi.org/10.1136/jnnp.47.5.496>
- Faria-Fortini, I., Michaelsen, S. M., Cassiano, J. G., & Teixeira-Salmela, L. F. (2011). Upper extremity function in stroke subjects: Relationships between the international classification of functioning, disability, and health domains. *Journal of Hand Therapy*, 24(3), 257–265. <https://doi.org/10.1016/j.jht.2011.01.002>
- Favetta, M., Romano, A., Valè, N., Cieslik, B., Federico, S., Girolami, A., Mazzarotto, D., Pregolato, G., Righetti, A., Salvalaggio, S., Castelli, E., Smania, N., Bargellesi, S., Kiper, P., & Petrarca, M. (2023). A scoping review of scientific concepts concerning motor recovery after stroke as employed in clinical trials. *Frontiers in Neurology*, 14, 1221656. <https://doi.org/10.3389/fneur.2023.1221656>
- Fugl-Meyer, A. R., Jääskö, L., Leyman, I., Olsson, S., & Steglind, S. (2011). The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. *Journal of Rehabilitation Medicine*, 7(1), 13–31. <http://www.ncbi.nlm.nih.gov/pubmed/1135616>. <https://doi.org/10.2340/1650197711331>
- Gabel, C. P., Yelland, M., Melloh, M., & Burkett, B. (2009). A modified QuickDASH-9 provides a valid outcome instrument for upper limb function. *BMC Musculoskeletal Disorders*, 10, 161. <https://doi.org/10.1186/1471-2474-10-161>
- Grefkes, C., Grefkes, C., Fink, G. R., & Fink, G. R. (2020). Recovery from stroke: Current concepts and future perspectives. *Neurological Research and Practice*, 2(1), 17. <https://doi.org/10.1186/s42466-020-00060-6>
- Hair, J. F., Babin, B. J., Black, W. C., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning, Inc.
- Harris, J. E., & Eng, J. J. (2006). Individuals with the dominant hand affected following stroke demonstrate less impairment than those with the nondominant hand affected. *Neurorehabilitation and Neural Repair*, 20(3), 380–389. <https://doi.org/10.1177/1545968305284528>
- Hosmer, D. W., Lemeshow, S., & Sturdivant, R. X. (2013). *Applied logistic regression*. Wiley. <https://doi.org/10.1002/9781118548387>
- Hudak, P. L., Amadio, P. C., Bombardier, C., Beaton, D., Cole, D., Davis, A., Hawker, G., Katz, J. N., Makela, M., Marx, R. G., Punnett, L., & Wright, J. (1996). Development of an upper extremity outcome measure: The DASH (disabilities of the arm, shoulder, and head). *American Journal of Industrial Medicine*, 29(6), 602–608. [https://doi.org/10.1002/\(SICI\)1097-0274\(199606\)29:6<602::AID-AJIM4>3.0.CO;2-L](https://doi.org/10.1002/(SICI)1097-0274(199606)29:6<602::AID-AJIM4>3.0.CO;2-L)
- Hussain, M., Fatima, A., Ahmad, A., & Gilani, S. A. (2022). Effects of task oriented rehabilitation of upper extremity after stroke: A systematic review. *Journal of the Pakistan Medical Association*, 72(7), 1406–1415. <https://doi.org/10.47391/JPM.A.3864>
- Jonsdottir, J., Thorsen, R., Aprile, I., Galeri, S., Spannocchi, G., Beghi, E., Bianchi, E., Montesano, A., & Ferrarin, M. (2017). Arm rehabilitation in post stroke subjects: A randomized controlled trial on the efficacy of myoelectrically driven FES applied in a task-oriented approach. *PLOS ONE*, 12(12), e0188642. <https://doi.org/10.1371/JOURNAL.PONE.0188642>
- King, B. M., Rosopa, P., & Minium, E. W. (2018). *Statistical reasoning in the behavioral sciences* (7th ed.). John Wiley & Sons, Inc. <https://www.wiley.com/en-us/Statistical+Reasoning+in+the+Behavioral+Sciences%2C+7th+Edition-p-9781119379737>
- Kinney, A. R., Eakman, A. M., & Graham, J. E. (2020). Novel effect size interpretation guidelines and an evaluation of statistical power in rehabilitation research. *Archives of Physical Medicine and Rehabilitation*, 101(12), 2219–2226. <https://doi.org/10.1016/j.apmr.2020.02.017>
- Kwakkel, G., & Kollen, B. J. (2013). Predicting activities after stroke: What is clinically relevant? *International Journal of Stroke*, 8(1), 25–32. <https://doi.org/10.1111/j.1747-4949.2012.00967.x>
- Kwakkel, G., & Kollen, B. (2015). Predicting activities after stroke. In *Oxford textbook of neurorehabilitation* (pp. 24–34). Oxford University Press. <https://doi.org/10.1093/med/9780199673711.003.0004>
- Lee, C. Y., & Howe, T. H. (2024). Effectiveness of activity-based task-oriented training on upper extremity recovery for adults with stroke: A systematic review. *American Journal of Occupational Therapy*, 78(2), 7802180070. <https://doi.org/10.5014/ajot.2024.050391>
- Lewthwaite, R., Winstein, C. J., Lane, C. J., Blanton, S., Wagenheim, B. R., Nelsen, M. A., Dromerick, A. W., & Wolf, S. L. (2018). Accelerating stroke recovery: Body structures and functions, activities, participation, and quality of life outcomes from a large rehabilitation trial. *Neurorehabilitation and Neural Repair*, 32(2), 150–165. <https://doi.org/10.1177/1545968318760726>
- Lima, R. C. M., Nascimento, L. R., Michaelsen, S. M., Polese, J. C., Pereira, N. D., & Teixeira-Salmela, L. F. (2014). Influences of hand dominance on the maintenance of benefits after home-based modified constraint-induced movement therapy in individuals with stroke. *Brazilian Journal of Physical Therapy*, 18(5), 435–444. <https://doi.org/10.1590/bjpt-rbf.2014.0050>
- Lin, J.-H., Hsu, M.-J., Sheu, C.-F., Wu, T.-S., Lin, R.-T., Chen, C.-H., & Hsieh, C.-L. (2009). Psychometric comparisons of 4 measures for assessing upper-extremity function in people with stroke. *Physical Therapy*, 89(8), 840–850. <https://doi.org/10.2522/ptj.20080285>
- Lyle, R. C. (1981). A performance test for assessment of upper limb function in physical rehabilitation treatment and research. *International Journal of Rehabilitation Research*, 4(4), 483–492. <https://doi.org/10.1097/00004356-198112000-00001>
- Metcalf, C., Adams, J., Burridge, J., Yule, V., & Chappell, P. (2007). A review of clinical upper limb assessments within the framework of the WHO ICF. *Musculoskeletal Care*, 5(3), 160–173. <https://doi.org/10.1002/msc.108>
- Moore, D. S., Notz, W. I., & Fligner, M. A. (2015). *The basic practice of statistics* (7th ed.). W. H. Freeman and Company.
- Murphy, M. A., Resteghini, C., Feys, P., & Lamers, I. (2015). An overview of systematic reviews on upper extremity outcome

- measures after stroke. *BMC Neurology*, 15(1), 29. <https://doi.org/10.1186/s12883-015-0292-6>
- Page, S. J., Fulk, G. D., & Boyne, P. (2012). Clinically important differences for the upper-extremity Fugl-Meyer Scale in people with minimal to moderate impairment due to chronic stroke. *Physical Therapy*, 92(6), 791–798. <https://doi.org/10.2522/ptj.20110009>
- Park, C. H., & Kim, M. S. (2023). Stratified predictions of upper limb motor outcomes after stroke. *Frontiers in Neurology*, 14, 1323529. <https://doi.org/10.3389/fneur.2023.1323529>
- Perini, G., Bertoni, R., Thorsen, R., Carpinella, I., Lencioni, T., Ferrarin, M., & Jonsdottir, J. (2021). Sequentially applied myoelectrically controlled FES in a task-oriented approach and robotic therapy for the recovery of upper limb in post-stroke patients: A randomized controlled pilot study. *Technology and Health Care*, 29(3), 419–429. <https://doi.org/10.3233/THC-202371>
- Phan, H. T., Blizzard, C. L., Reeves, M. J., Thrift, A. G., Cadilhac, D. A., Sturm, J., Heeley, E., Otahal, P., Vemmos, K., Anderson, C., Parmar, P., Krishnamurthi, R., Barker-Collo, S., Feigin, V., Bejot, Y., Cabral, N. L., Carolei, A., Sacco, S., Chausson, N., ... Gall, S. L. (2018). Factors contributing to sex differences in functional outcomes and participation after stroke. *Neurology*, 90(22), e1945–e1953. <https://doi.org/10.1212/WNL.0000000000005602>
- Schiefelbein, M. L., Salazar, A. P., Marchese, R. R., Rech, K. D., Schifino, G. P., Figueiredo, C. S., Cimolin, V., & Pagnussat, A. S. (2019). Upper-limb movement smoothness after stroke and its relationship with measures of body function/structure and activity – A cross-sectional study. *Journal of the Neurological Sciences*, 401, 75–78. <https://doi.org/10.1016/j.jns.2019.04.017>
- Soto, A., Guillén-Grima, F., Morales, G., Muñoz, S., Aguinaga-Ontoso, I., & Fuentes-Aspe, R. (2022). Prevalence and incidence of ictus in Europe: systematic review and meta-analysis. *Anales del Sistema Sanitario de Navarra*, 45(1), e0979. <https://doi.org/10.23938/ASSN.0979>
- Steyerberg, E. W., Vickers, A. J., Cook, N. R., Gerdts, T., Gonen, M., Obuchowski, N., Pencina, M. J., & Kattan, M. W. (2010). Assessing the performance of prediction models: A framework for traditional and novel measures. *Epidemiology*, 21(1), 128–138. <https://doi.org/10.1097/EDE.0b013e3181c30fb2>
- Thabane, L., Mbuagbaw, L., Zhang, S., Samaan, Z., Marcucci, M., Ye, C., Thabane, M., Giangregorio, L., Dennis, B., Kosa, D., Debono, V. B., Dillenburg, R., Fruci, V., Bawor, M., Lee, J., Wells, G., & Goldsmith, C. H. (2013). A tutorial on sensitivity analyses in clinical trials: The what, why, when and how. *BMC Medical Research Methodology*, 13(1), 92. <https://doi.org/10.1186/1471-2288-13-92>
- Thakkar, H. K., Liao, W. W., Wu, C. Y., Hsieh, Y. W., & Lee, T. H. (2020). Predicting clinically significant motor function improvement after contemporary task-oriented interventions using machine learning approaches. *Journal of NeuroEngineering and Rehabilitation*, 17(1), 1–10. <https://doi.org/10.1186/S12984-020-00758-3/TABLES/3>
- Timmermans, A. A. A., Spooren, A. I. F., Kingma, H., & Seelen, H. A. M. (2010). Influence of task-oriented training content on skilled arm-hand performance in stroke: A systematic review. *Neurorehabilitation and Neural Repair*, 24(9), 858–870. <https://doi.org/10.1177/1545968310368963>
- Tomczak, M., & Tomczak, E. (2014). The need to report effect size estimates revisited. An overview of some recommended measures of effect size. *TRENDS in Sport Sciences*, 1(21), 19–25.
- Van der Lee, J. H., De Groot, V., Beckerman, H., Wagenaar, R. C., Lankhorst, G. J., & Bouter, L. M. (2001). The intra- and inter-rater reliability of the action research arm test: A practical test of upper extremity function in patients with stroke. *Archives of Physical Medicine and Rehabilitation*, 82(1), 14–19. <https://doi.org/10.1053/APMR.2001.18668>
- van der Lee, J. H., Roorda, L. D., Beckerman, H., Lankhorst, G. J., & Bouter, L. M. (2002). Improving the action research arm test: A unidimensional hierarchical scale. *Clinical Rehabilitation*, 16(6), 646–653. <https://doi.org/10.1191/0269215502cr534oa>
- Winstein, C. J., Stein, J., Arena, R., Bates, B., Cherney, L. R., Cramer, S. C., Deruyter, F., Eng, J. J., Fisher, B., Harvey, R. L., Lang, C. E., MacKay-Lyons, M., Ottenbacher, K. J., Pugh, S., Reeves, M. J., Richards, L. G., Stiers, W., & Zorowitz, R. D. (2016). Guidelines for Adult Stroke Rehabilitation and Recovery. *Stroke*, 47(6), e98–e169. <https://doi.org/10.1161/STR.0000000000000098>
- Woytowicz, E. J., Rietschel, J. C., Goodman, R. N., Conroy, S. S., Sorkin, J. D., Whittall, J., & McCombe Waller, S. (2017). Determining levels of upper extremity movement impairment by applying a cluster analysis to the fugl-Meyer assessment of the upper extremity in chronic stroke. *Archives of Physical Medicine and Rehabilitation*, 98(3), 456–462. <https://doi.org/10.1016/j.apmr.2016.06.023>