Development and Rasch validation of an observational kinematic-based scale of upper limb movement impairment in stroke patients: the Functional ASsessment Test for Upper Limb (FAST-UL).

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ABSTRACT

Background

In clinical practice of post stroke rehabilitation, the assessment of upper limb function is important to improve patient's impairment definition and to evaluate the effectiveness of specific interventions. Clinical scales focused on impairment evaluation generally require a considerable amount of time to be administered and are not functionally oriented. Observational kinematic-based clinical outcome measures could allow the characterization of arm and hand motor impairments, improving the assessment of goal-directed functional-oriented motor tasks.

Objective

Conceptualize and develop a quick observational kinematic-based clinical tool, the Functional ASsessment Test for Upper Limb (FAST-UL), evaluating upper limb motor performance impairment in post-stroke patients.

Methods

A panel of experts defined the underlying neurophysiological concepts of the FAST-UL. Five items measured through a 4-level ordinal scale were identified: Hand to Mouth (HtM), Reach to Target (RtG), Prono-Supination (PS), Grasp and Release (GR) and Pinch and Release (PR). FAST-UL was applied on 188 post-stroke patients and Rasch analysis through a partial credit model (PCM) was performed to assess the structure and its psychometric properties.

Results

The Cronbach's α equal to 0.96 was indicative of an acceptable internal consistency, and the reliability, as measured through the Person Separation Index equal to 0.87, was good. The FAST-UL tool was unidimensional. A Rasch PCM was fitted, and all the FAST-UL items were found to fit well. The easiest to perform FAST-UL item was the HtM movement while the most difficult was the PR movement.

Conclusions

The FAST-UL is a quick, easy-to-administer kinematic-based assessment tool of upper limb motor impairment in post-stroke patients with good item-level psychometric properties.

KEYWORDS:

Stroke, Upper Limb Impairment, Kinematic-based Outcome Measures, Rasch Analysis

INTRODUCTION

Stroke is the leading cause of acquired adult disability, resulting in a large proportion of survivors (up to 85%) experiencing some degree of paresis of the upper limb[1]. Hemiparesis may be associated with decreased strength and sensation, increased muscle tone, loss of interjoint coordination and impaired control of voluntary movement resulting in slow, imprecise and uncoordinated task-related movement[2]. These impairments often causes limitations in activities of daily living and may decrease the quality of life[3].

Assessment of upper limb function is central for improving clinical practice and for evaluating efficacy of rehabilitation interventions. Several systematic reviews, guidelines and consensus-based recommendations have evaluated the psychometric properties and clinical feasibility of upper limb outcome measures in stroke rehabilitation[4-6]. Other reviews described the different functioning domains (namely body function, activities and participation) covered by each measure[6], and provided an overview of the frequency of use in clinical practice and research[7]. Within the International Classification of Functioning (ICF) body structure/function level, a variety of assessment scales evaluates motor impairment after stroke, by capturing aspects such as joint range of motion, strength, synergistic execution of movements, gross motor capabilities, object manipulation[8]. Among them, the Fugl-Meyer Test for Upper Limb (FMT-UL) is the most commonly outcome measure used in stroke rehabilitation research[7].

However, these scales generally require a considerable amount of time and may lack of consistency in repeated measurements[9]. In addition, they mainly focus on task accomplishment without focusing on the extent and patterns of movements[10].

A kinematic-based clinical evaluation tool could simply allow to characterize arm and hand motor impairments, thus improving the assessment of motion deficits in stroke patients. Demers et al. recently proposed observational kinematics as an easy and low cost approach to assess upper limb movement in clinical practice[2]. In a study by Berhardt and colleagues, the observation of kinematics allowed moderate to high accuracy of judgement on several kinematic aspects of a transport task in stroke patients[11]. The Reaching Performance Scale for Stroke (RPSS) is one of the few measures that assesses movement patterns through a numerical scoring system of upper limb and trunk movements and compensations during two reach-to grasp tasks.[12-14]

There is, however, a lack of kinematic-based clinical outcome measures for the description of other functional movements of the upper limb. New clinical behavioral indicators providing a more comprehensive understanding of stroke-related functional-oriented motor deficits may led to the development of new and better patient-centered therapies by targeting specific motor deficits[15].

The aim of our study is to conceptualize and develop a quick observational kinematic-based clinical tool, namely the Functional ASsessment Test for Upper Limb (FAST-UL), evaluating upper limb motor performance impairment in post-stroke patients. The FAST-UL tool is herewith evaluated by using the Rasch measurement theory.

METHODS

Conceptualization and Development of the FAST-UL tool

The development of a new scale firstly requires the establishment of a conceptual framework. A modified Delphi approach was followed to define the underlying neurophysiological concepts who were taught to influence the validity of the scale, i.e. the degree to which the instrument measures the construct it purports to measure. A first consensus meeting among experts was held in 2018 in Milan, participants were physiatrists, neurologists, neurophysiologists, bioengineers. All had extensive experience in the management of patients with neurological diseases and sequelae, including motor function deficits treatment and movement analysis. The panel of experts critically reviewed the existing literature and guidelines, discussed about content validity as well as possible items and their related scoring criteria. In fact, the final aim of the panel was to develop a concise motor scale addressing the need for a quickly administered, rigorous, bedside measure of active upper limb motor ability in stroke patients. A list of items was developed through iteration and consensus. Current best-practice outcome measures at impairment level were explored for commonalities with kinematic analysis tasks requirements[16-18]. Items were selected to ensure that basic components of movement in each upper extremity joint were captured and integrated in multijoint movements (i.e. intersegmental movements put together in sequential fashion), as to accomplish a functional goal.

A second consensus meeting was held in 2019. On the basis of personal clinical experience and a further extensive discussion within the panel, a consensus was reached on the tasks to be included in the FAST-UL tool.

The FAST-UL tool

The FAST-UL is a kinematic-based scale of upper limb movement impairment in stroke patients, composed of 5 items measured through a 4-level ordinal scale (See Supplementary Material 1). The items identified by the panel of experts are Hand to Mouth (HtM), Reach to Target (RtT), Prono-Supination (PS), Grasp and Release (GR) and Pinch and Release (PR).

The RtT and HtM movements are well established paradigms for upper limb kinematic evaluations; these movements are used to assess upper limb functions in healthy people and individuals with neurological diseases[19,20].

In literature, RtT and reach to grasp are the most analyzed tasks with kinematic analysis in stroke patients with upper limb deficits[17]. Only the RtT task was selected by the panel of experts and included in the FAST-UL because it is the precursor component of most everyday upper limb tasks. Although the reach to grasp includes several kinematic subtasks accounting for different motor skills, it may become too complex for individuals with moderate or severe impairment, which could decrease the amount of participants able to accomplish the task.

The PS task was selected since it is one of the commonly trained movements in conventional and robotic[21] post-stroke therapies. The pronated or supinated forearm are common clinical patterns of arm spasticity and are the goal of many post-stroke upper limb focal treatments[22].

Only two different prehension patterns were selected among those described in the literature[23] in order to make the evaluation protocol quick to perform: a cylindrical and a tip grasp. The former is a power grasp (Grasp and Release, GR) requiring thumb abducted, the latter is a precision pinch (Pinch and

Release, PR)[24]. Human hand prehension is significantly influenced by object shape and size, relative position between hand and object, and action goal (the movement task)[25]. Arm motor impairments, and in particular an inefficient activation or weakness of the shoulder muscles, are other factors deeply impacting hand grasp behavior[26]. To better assess post stroke hand prehension patterns impairments, shoulder involvement was excluded. The tasks were developed in order to exploit a coordinated multijoint movement across distal segments of the upper limb during a goal directed task requiring active grasping, lifting and releasing of objects. It was established to use simple everyday objects readily available (a glass and a pen) in the execution of the tasks since objects manipulation is closer to functional aspects. The movement depends on the participant's capacity at body function level of the ICF, and the rating depend on how the task is accomplished.

Study participants

A total of 188 patients with a first stroke diagnosis were consecutively recruited as in- or out-patients at Villa Beretta Rehabilitation Center, located in Costa Masnaga in the province of Lecco, Italy, between April 2021 and October 2021 (Table 1).

Inclusion criteria:

- 18 years of age or older;
- Ischemic or hemorrhagic first stroke diagnosed by medical records;
- Post-acute (≤ 6 months from the acute event) or chronic (> 6 months) stroke diagnosis;
- Being able to sign an informed consent for study participation;
- Being able to follow the instructions required to complete the FAST-UL tool;
- Absence of pain in the paretic upper limb;
- Absence of passive range of movements limitations in the affected upper limb.

Exclusion criteria:

- Patient who had conditions other than stroke that affect upper limb function (other neurological conditions, orthopaedic or rheumatic disorders of the upper limb).

The study was approved by the local Ethical Commitee Comitato Etico dell'Insubria (24/2021) in April 27, 2021. All the patients gave informed consent for study participation.

Statistical analysis

Rasch analysis

The polytomous Rasch analysis was applied to assess the structure and psychometric properties of the FAST-UL. Rasch models[27] belongs to a family of models called "Item Response Theory", allowing to identify the relative difficulty of each FAST-UL item, and separately determines each individual's relative ability. Since FAST-UL items are polytomous and share the same number of response categories, a rating scale model (RSM) or a partial credit model (PCM) could be fitted. Since FAST-UL items difficulty could not be assumed to be equal, a PCM model was fitted[27]. However, a sensitivity analysis to confirm the choice of the PCM over the RSM was carried out by using a data-driven approach based on the likelihood ratio test.

The FAST-UL is composed of 5 items measured through a 4-level ordinal scale, which determines 3 transition points, the so called thresholds between adjacent response categories revealing the point where the likelihood of choosing either response category is the same. The Rasch analysis assessed the item difficulty hierarchical order of the items by identifying whether response categories and thresholds were consistent with a logical progression from "easy to hard"[28]. Item Characteristics Curves (ICC) were displayed to map the person relative probability for endorsing a given item response and the its difficulty. Results of the Rasch analysis were finally displayed through the Wright person-item map, a plot showing the location of FAST-UL items and thresholds along with person parameters.

The two assumptions of the Rasch analysis are unidimensionality[29] and local independence[30]. Unidimensionality means that the FAST-UL items measures only one construct[29], in this case, motor function of the affected upper limb. Local independence means that FAST-UL items are independent of each other[30], i.e. a performance in one item should never lead to any other item score.

All the analyses were carried out with the eRm R package[31].

Assessment of unidimensionality

A principal component analysis (PCA) was carried out to assess FAST-UL unidimensionality[32]. The PCA allowed to identify a limited number of principal components (factors) - i.e. linear combinations of the FAST-UL items- able to explain a large amount of variance in the data. To test for unidimensionality, we examined PCA eigenvalues, factor loading statistics and the scree plot, a graphical tool showing the amount of variance explained by each factor. In addition, the Kaiser rule[33] was used as a criteria for retaining only those principal components whose eigenvalues are greater than 1.0. To satisfy unidimensionality, one PCA must explain the majority of variance.

Evaluation of internal consistency

The Cronbach's α and its 95% confidence interval (CI) was used to examine internal consistency, a measure of the extent to which FAST-UL items measure different aspects of the same construct. A Cronbach $\alpha \geq 0.90$ is indicative of acceptable internal consistency[34]. We also evaluated the person separation index (PSI), a measure of reliability whose interpretation is similar to the Cronbach's α. A cut-off value of 0.80 is considered as a minimum acceptable level of reliability[35].

Assessment of local independence

Local independence means that an individual's response to a given item is not related (independent) to the response of any other item. The violation of local independence[30] among FAST-UL items could have an impact on internal consistency. Local independence can be detected by examining the FAST-UL items standardized residual correlation matrix. Residuals are differences between observed and Rasch model-based expected response to each FAST-UL item. Although there is no consensus in the literature, to satisfy local independence, correlation of standardized residual values must be less than 0.3[30].

Fit statistics

To assess item fit statistics, we evaluated the infit and outfit statistics of the items, reported in terms of mean square standardized residuals (MnSq)[35]. According to Linacre[36], an acceptable range for MnSq ranges between 0.5 and 1.5. Higher values indicate that an item is being inaccurately scored or belongs to a construct that is different from that represented by the other items of the instrument, while lower values suggest that an item is “too perfect,” showing less variation than would be expected in real-life applications[36].

In addition, the item-trait interaction chi-square statistics[37] was assessed, and a p-value greater than 0.05 was deemed to be indicative of an adequate fit. However, as recently suggested by Müller[38], parametric bootstrap is recommended to calculate valid p-values. Briefly, 1000 simulated FAST-UL datasets were generated starting from the PCM item and person parameter estimates in order to generate the sampling distribution of the item-trait interaction. The bootstrap item-trait statistics p-value was then computed as proportion of simulated dataset whose item-trait statistics was greater or equal than the observed one[38].

Floor and ceiling effects

Floor and ceiling effects were quantified as proportion of patients achieving the minimum, i.e. 0, and maximum total score, i.e. 15, respectively. Floor and ceiling effects over 15% could be considered indicative of an inappropriate measurement model[39].

Consideration on the study sample size

A sample size of 100 has been shown to be adequate to achieve an item calibration of ±0.5 logits with a 95% confidence interval[40]. In our study we decided to enroll all consecutive in- or out-patients admitted at Villa Beretta (Costa Masnaga, province of Lecco) with a first stroke diagnosis, without focusing on a pre-definite target, in order to achieve a more than adequate sample size. We finally enrolled a total of 188 consecutive patients.

RESULTS

Demographic Characteristics

The demographic characteristics of the study patients are summarized in Table 1. Mean age was 65.2±17.7 years, there were 114 (61%) males and 74 (39%) females. The study sample was balanced in terms of stroke type, with 91 (48%) patients with ischemic and 97 (52%) with hemorrhagic stroke.

125 (66%) of the study patients were in the sub-acute phase (180 days or less from the acute event) and 63 (34%) in the chronic phase (distance from the acute event greater than 180 days).

FAST-UL statistics and flooring/ceiling effect

Table 2 shows the frequency of each FAST-UL item. A total of 39 patients (21%) received the minimum FAST-UL score of 0 points while 29 (15%) patients the maximum score of 15 points. Thus, the FAST-UL may possibly has a floor effect for patients with poor upper limb motor function.

Evaluation of internal consistency

The Cronbach's α was 0.96 (95% CI, 0.94-0.97), indicative of an acceptable internal consistency. Similarly, the PSI was equal to 0.87, showing a good reliability.

Assessing of unidimensionality

The PCA revealed that the first principal component explained more than 85% of variance (see the the Supplementary online material 2). The Kaiser rule confirmed that the FAST-UL tool was unidimensional, with the first eigenvalues equal to 4.26.

Rasch analysis

A Rasch PCM was fitted. The likelihood ratio test confirmed that the PCM had a better fit than the RSM (χ^2=24.2, 8 degrees of freedom, $p<0.01$).

Table 3 shows the FAST-UL item infit and outfit MnSq for each item along with item difficulties expressed in logits. Infit and Outfit MnSq values ranged between 0.5 and 1.5, with the associated item-trait interaction chi-square statistics bootstrap p-values greater than 0.05 for all FAST-UL items. This means that all the items were found to fit well. Moreover, all the items had an optimal discrimination potential, with corrected item-test correlation greater than 0.8. The percentage of person misfitting was very low and equal to 2.5%, with only 5 out of 188 persons that did not demonstrate acceptable fit to the Rasch PCM. ICC for each FAST-UL item are displayed in Supplementary Material 3. For the PR movement, the probability that the object is pinched and lifted but it falls, or the task is completed using alternative pinching strategies (category 2) slightly exceeded the probability to complete the task (category 3). This means that the completion of the PR movement is difficult even for patients with higher abilities.

The easiest to perform FAST-UL item was the HtM movement while the most difficult was the PR movement. The person-item map and the person's ability are plotted in Figure 1. Item scores are 0 if a participant's ability is on the left side of the left white dot, 1 if a participant's ability is between two white dots between 1 and 2, 2 if a participant's ability is between 2 and 3 and 3 if a participant's ability is on the right side of the right white dot.

Assessing of local independence

The correlation matrix of standardized Rasch residuals mainly showed negative correlations, except for correlation between RtT and HtM (ρ=0.13), and between GR and PR (ρ=0.34). For the latter, there was a slight evidence of local dependency.

DISCUSSION

We developed the FAST-UL, an easy-to-administer kinematic-based assessment tool of upper limb motor impairment in post-stroke patients, and we assessed its psychometric properties using the Rasch analysis.

The 5 items of the FAST-UL contribute to the measurement of a single construct (motor functions of the upper limb). The Cronbach'alpha and its 95% confidence interval (CI), along with the PSI, were indicative of adequate internal consistency. The item response theory statistical techniques revealed that all the items of the FAST-UL fitted the Rasch model, thereby confirming the internal construct validity and the unidimensionality of the scale.

The items of the FAST-UL show a difficulty order that the Rasch-generated item-difficulty order maintains consistent independently by person ability[41,42]. In the person-item map, person ability and item difficulty are plotted on the same graph; the combination of person ability and item difficulty shows the relation between item easiness for subjects with low ability and item difficulty for subjects with high ability.

The item-difficulty logits showed that the Hand to Mouth Movement was the easiest item to perform while the Pinch and Release Movement was the most difficult one. Individuals with low FAST-UL scores performed more easily items that recall global synergies patterns (i.e. the Hand to Mouth task) whereas individuals with higher scores successfully performed items that require dexterous manipulation (i.e. the pincher grasp). This finding is in line with current literature, suggesting that active distal UE movement is an ability exhibited by only a minority of post-stroke patients[43,44].

According to the person-item map, the reach to target movement was more difficult than the Hand to Mouth movement because greater shoulder elevation with active elbow and finger extension is required. The prono-supination movement was among the moderate difficult items, reflecting the difficulty that stroke patients encounter in forearm alternating movements. The cylindrical grasp was easier than the pincer one and these results are consistent with those of other studies[41,28], confirming that gross movements with the whole hand may be simpler than coordinated movements using digits in post stroke patients.

Given that all the items test proximal-distal coordinated movements against gravity, it is not surprising that lower scores are associated with reduced arm-hand strength and/or alternative/compensatory movement strategies while higher scoring is associated with near-normal ability for movements requiring better motor control. This aspect could explain why a multijoint movement against gravity such as the hand to mouth movement may result easier than a pincher grasp performed with elbow stabilization on the table for stroke patients. Once again, these findings underline the difficulty that patients experience in regaining qualitative distal movements after stroke. Moreover, 24 patients (13%) achieved the best score in the reaching task (adequate shoulder flexion, elbow and finger extension), but showed problems in prehension patterns. Although grasping and postural control actions often accompany a reaching movement, these elements are controlled by distinct motor programs ([45]). These findings support the theoretical construct that reach and grasp movement patterns need to be assessed separately in motor impairment evaluation tools. A reach to grasp task could be more important in functional scales at activity level.

The FAST-UL could supply clinical behavioral indicators that provide a more comprehensive understanding of stroke-related motor deficits. The functional nature of the tasks allow clinicians to better assess movements required for functional tasks, unlike the movements performed during other impairments tools. It is well known that many impairment outcome measures asses mostly abstract movements and limb postures that have little to no relevance to the subject's movements in daily life. In our opinion, functional movement evaluation is very important because can be used as an indirect measure of upper limb function in daily life[46]. Since it is well established that motor performance is influenced by the task, we strongly believe in the importance of a precise motor impairment evaluation in goal oriented movements rather than in non-functional movements[17,47]. So, it is probable that a person's response to an assessment item reflects a dynamic interaction of neural activity with task-specific contextual variables[47]. Each item of the scale evaluates different combinations of upper limb movements in terms of active range of motion and strength, and assess in a standardized manner goal-directed patterns of movement predictive of functional aspects (i.e. functional tasks of everyday activity), potentially useful to goal setting and treatment planning.

The theoretical construct of the FAST-UL, supported by Rasch analysis, was developed upon neurophysiological basis that captures the content of upper limb kinematic evaluations.

The use of this clinical assessment tool could allow better correlations with instrumental analysis (i.e. 3D motion systems, robotics) of the upper limb, bridging the gap between clinical motor assessments and the kinematic characterization of various upper limb movements performed in daily life[47]. Recently, the second Stroke Recovery and Rehabilitation Roundtable task force suggested a standardized kinematic and kinetic measurement protocol including four performance assays (i.e. 2D planar reaching, finger individuation, grip strength, and precision grip) at body function level and one functional task (3D drinking task) at activity level[16]. Three out of the four instrumental assays at impairment level cover the same conceptual construct of the items included in the FAST-UL (reaching, grasp and pinch tasks). Shwarz and colleagues[16] outlined the need to better evaluate convergent validity of upper limb kinematics with clinical instruments that capture the same physiological construct. Consequently, clinical outcome measures that are comparable to instrumental outcome measures could be a key step toward integrating technology into clinical practice[18].

There is a growing literature suggesting a research priority to develop standardized outcome measures distinguishing motor compensation from restitution[48]. Although 3-dimensional motion capture represents the gold standard for quantifying movement compensations, a kinematic-based observational analysis of basic movements of the upper limb could help achieve a better understanding of the relationship between movement quality and ability to perform functional activities[10]. Currently, it is under investigation a further development of the FAST-UL adding quality aspects to the motor items of the scale. Inclusion of secondary measures to track quality movements might boost data complexity and time to administer, so the panel established to keep the two assessment separate.

In fact, the FAST-UL was originally developed in order to achieve a concise motor scale addressing the need for a quickly administered (3-5 minutes) bedside measure of active upper limb motor ability. It takes less time to administer than the FMA[49], the most widely used assessment tool of upper limb motor impairment in stroke rehabilitation research[7]. This explains why a short form (6 items for the upper limb) of the FMA was developed and validated with Rash analysis[50]. However, although reliable, valid and widely spread in research, the FMA examines synergy patterns that no longer form the basis for many functionally oriented movements, and treatments as well. Recently, Schwarz and colleagues raised the question on how far this outcome measure can sensitively capture changes on the body function level when performing daily life tasks[46].

Study Limitations

We investigated the psychometric properties of the FAST-UL considering patients enrolled in a single rehabilitation center. This limits the generalizability of our findings and it is a call for future researches in other rehabilitation centers and settings. The observed floor effects, due to a relatively large proportion of patients (21%) achieving the minimum FAST-UL score, may have had an impact on internal consistency. In addition, the grasp and release and the pinch and release movements showed a residual positive correlation that may be indicative of local dependency. However, we decided not to delete one of the item. From a clinical perspective, items with similar difficulties like grasp and pinch may provide important informations on upper limb motor function to clinicians, and item removal should be approached with caution[51].

As a further limitation, we did not carry out a differential item functioning (DIF) analysis to assess whether selected characteristics of the study sample (e.g. age, sex, stroke type etc.) could have an impact on functioning of one or more FAST-UL item.

This analysis focuses only on certain psychometric properties of the FAST-UL. Other important psychometric properties (ie, intra-interrater reliability, clinical and instrumental convergent validity, responsiveness) need to be addressed.

Conclusion

The FAST-UL is a quick, easy-to-administer kinematic-based assessment tool of upper limb motor impairment in post-stroke patients with good item-level psychometric properties, including dimensionality, fit statistics and item difficulty hierarchy. Since the test is concise and does not require specialized materials and training, it could be used for routine bedside examination in addition to classical neurological examinations that typically address global or segmental residual active movements outside a functional context.

The Rasch analysis of the FAST-UL shows that the items have strong item-level measurement properties and thus the scores can be easily interpreted and compared by clinicians. The tool allows to get a rapid and immediate picture of motor function impairment during basic goal-directed functional-oriented motor tasks.

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Table 1. Characteristics of the study sample.

	n=188
Age (years)	65.2 (±17.7)
Gender	
Male	114 (61%)
Female	74 (39%)
Stroke type	
Ischemic	91 (48%)
Heamorragic	97 (52%)
Affected Side	
Right	96 (51%)
Left	92 (49%)
Condition	
Sub-acute	125 (66%)
Chronic	63 (34%)

Table 2. FAST-UL response items statistics.

Items		n (%)
HtM		
	0	44 (23%)
	1	24 (13%)
	2	30 (16%)
	3	90 (48%)
RtT		
	0	48 (26%)
	1	27 (14%)
	2	39 (21%)
	3	74 (39%)
PS		
	0	63 (34%)
	1	41 (22%)
	2	36 (19%)
	3	48 (25%)
GR		
	0	81 (43%)
	1	22 (12%)
	2	28 (15%)
	3	57 (30%)
PR		
	0	81 (43%)
	1	28 (15%)
	2	38 (20%)
	3	41 (22%)
Floor effect†		39 (21%)
Ceiling effect‡		29 (15%)

† Represents the proportion of patients with the minimum total score.

‡ Represents the proportion of patients with the maximum total score.

Abbreviations: GR=Grasp and Release; HtM=Hand to Mouth; PR=Pinch and Release; PS=Pronation and Supination; RtT=Reach to Target.

Table 3. Item difficulty parameters and fit statistics

Items	Difficulty (logits)	Infit MnSq (t statistic)	Outfit MnSq (t statistic)	Item-trait χ^2 statistic (df)	Item-trait bootstrap p	Discrimination
HtM		0.76 (-1.75)	0.63 (-1.62)	76.0 (119)	0.93	0.81
0	--					
1	-3.52 (0.54)					
2	-4.29 (0.58)					
3	-3.37 (0.53)					
RtT		0.77 (-1.82)	0.77 (-1.55)	92.1 (119)	0.89	0.83
0	--					
1	0					
2	-3.26 (0.49)					
3	-1.27 (0.47)					
PS		0.93 (-0.53)	0.88 (-0.85)	105.7 (119)	0.60	0.76
0	--					
1	-1.32 (0.33)					
2	0.34 (0.39)					
3	3.89 (0.53)					
GR		0.73 (-2.02)	0.74 (-1.01)	88.8 (119)	0.60	0.84
0	--					
1	0.48 (0.32)					
2	1.87 (0.43)					
3	4.76 (0.58)					
PR		0.77 (-1.77)	1.23 (0.99)	148.1 (119)	0.08	0.80
0	--					
1	0.36 (0.31)					
2	2.07 (0.42)					
3	6.20 (0.62)					

Abbreviations: df=degrees of freedom; GR=Grasp and Release; HtM=Hand to Mouth; MnSq=mean square standardized residuals; PR=Pinch and Release; PS=Pronation and Supination; RtT=Reach to Target.

Figure 1. Person-item map for the FAST-UL tool.

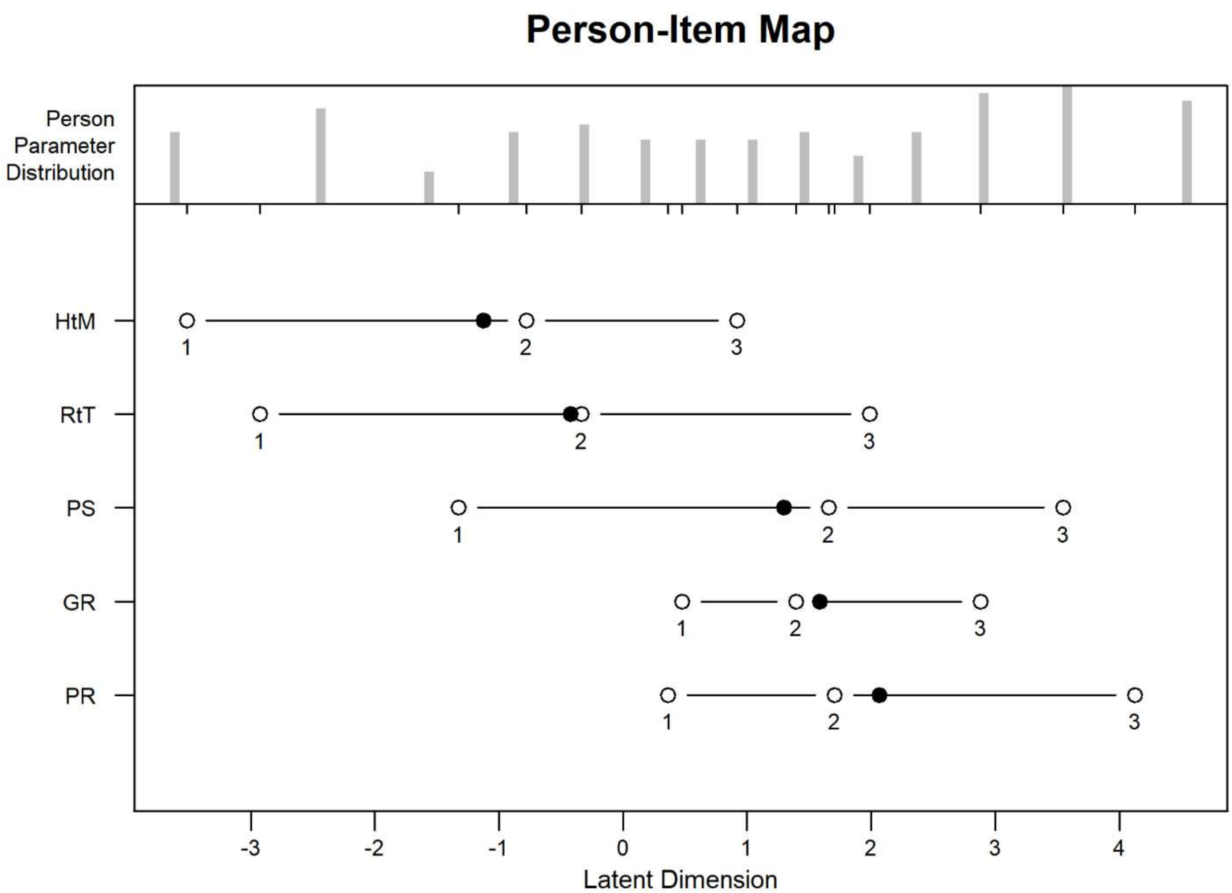


Figure 1 footnote. The horizontal axis of the lower panel represents item difficulty expressed in logits (latent dimension) while the horizontal axis of the upper panel is a parameter of the person's ability. The dot depicts the item difficulty measures and represents the location and thresholds defined for each item.

Supplementary Material 1. Description of the items of the FAST-UL tool.

<u>Hand-to-mouth (HtM) Movement</u>

Starting Position:
Patient seated on a standard chair without armrests.
Trunk leaning on the back support of the chair.
Both hands placed in pronated position on the ipsilateral middle thigh.
Both feet placed flat on the floor.
The head kept still in upright position
If patients have any difficulty in understanding instructions (i.e. aphasia) a visual demonstration is suggested.
For each of the 5 tasks of the FAST-UL, the subject at first performs the movement with the less affected UL and then with the affected one. The movement can be repeated 3 times and the best score of the three attempts is assigned.

Each subject is asked to move the hand towards the mouth, touch it with fingertips and return to the thigh. Motor task occurs without moving the trunk off the back support and without moving the head toward the hand.
Clinical score from 0 to 3 is provided by comparing affected side with less affected one as follows:

0 = no movement at all

1 = The movement task is not completed (less of 50% of the contralateral HtM movement).

2 = The movement task is not completed (more of 50% of the contralateral HtM movement but the mouth is not reached) or the movement task is completed with compensations. If the mouth is touched with the wrist or the palm or the movement is performed with head or trunk compensations (flexion of the head and trunk towards the hand) the score is 2.

3 = movement carried out at 100% of the contralateral HtM movement. HtM occurs with adequate shoulder flexion and abduction, elbow flexion, and forearm supination. The mouth is touched with fingertips.

0 1 1 2 2 3

<u>Reach to Target (RtT) Movement</u>

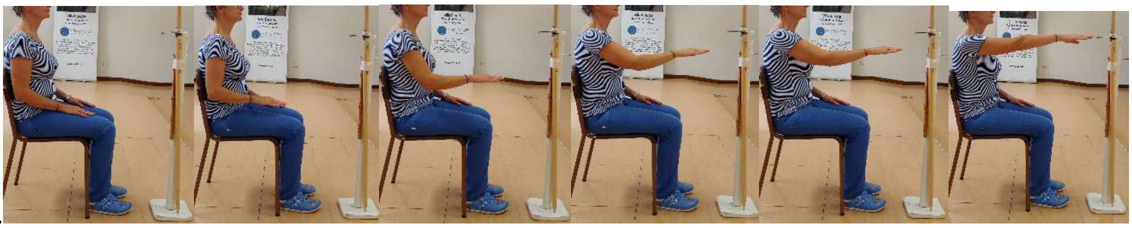
Same starting conditions of HtM movement.

Each subject is asked to move the hand toward a target (i.e. the hand of the examiner) located in front of the subject in the ipsilateral workspace at shoulder height, at a distance corresponding to 100% of the fully extended UL within arm's reach (less affected arm as reference). Participants have to reach, touch the target and return. Motor task occurs without moving the trunk off the back support.
Clinical score from 0 to 3 is provided by comparing affected side with less affected one as follows:
0 = no movement at all

1 = The movement task is not completed (less of 50% of the contralateral RtT movement).

2 = The movement task is not completed (more of 50% of the contralateral RtT movement but the target is not reached) or the movement task is completed with compensations (i.e. the trunk loses contact with the back support of the chair with forward displacement, shoulder flexion occurs with excessive scapular elevation, or shoulder excessive abduction). If the target is reached with trunk or shoulder compensations for inadequate elbow and finger extension the score is 2.

3 = movement performed at 100% of the contralateral RtT. The target is reached with adequate shoulder flexion, elbow, wrist and finger extension.



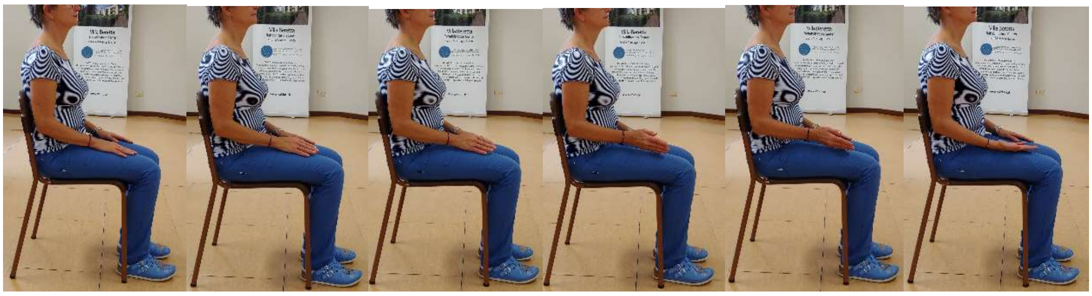
0 1 1 2 2 3

Prono-supination (PS) Movement
Same starting conditions of HtM movement.
Motor task occurs without moving the trunk anteriorly or laterally, the medial side of the homer is against the body, the forearm is fully pronated with the hand resting on the thigh.
Clinical score from 0 to 3 is provided by comparing paretic side with less affected one as follows:
0 = no movement at all

1 = The movement task is not completed (less of 50% of the contralateral PS movement).

2 = The movement task is not completed (more of 50% of the contralateral PS movement but the forearm is not fully supinated) or the movement task is completed with compensations (i.e. excessive trunk inclination, shoulder abduction. If the movement is completed with compensations at elbow, shoulder or trunk level the score is 2.

3 = movement performed at 100% of the contralateral PS (complete supination of the forearm with the dorsal part of the hand in contact with the thigh).



0 1 1 2 2 3

<u>Grasp and Release (GaR) Movement</u>

Starting position:
Patient seated on a standard chair
Hip and knees in 90° flexion, feet flat on the floor
Upper limb resting on a table in front of the patient with approximately 90° elbow flexion, forearm pronated and fingers in a relaxed extended and adducted position.

The subject performs a grasping movement of a cylindrical rigid glass (at least 6 cm diameter) placed proximally to an imaginary line connecting the distal joints of thumb and index finger. The subject is asked to grasp the glass, lift it at least 2 cm (elbow remains in contact with the table), and release it.
Clinical score from 0 to 3 is provided by comparing affected side with less affected one as follows:
0 = No movement. The grasp is not possible.

1 = The movement task is not completed (less of 50% of the task). Some prehension is possible but the grasp is not sufficiently stable to lift the object; the grasp can be performed with the use of the less affected hand only to stabilize the glass for inadequate hand/finger opening and the release is not possible. Some hand opening is required otherwise the score is 0

2 = The movement task is not completed (more of 50% of the task). The object is grasped and lifted but it falls or the task is completed using alternative grasping strategies (i.e. multi-pulpar, palmar, digito palmar; grasping and releasing of the object is possible with abnormal orientation of the wrist and fingers toward the object and the forearm is lifted off the table)

3 = The task is completed using the expected pattern (normal orientation of fingers or wrist toward the object, the grasp occurs with thumb and fingers in opposition, forearm supination, elbow flexion; thumb abduction and finger extension to release the object).

<u>Pinch and Release (PaR) Movement</u>

Same starting conditions of GaR movement

The patient performs a PaR movement of a pen placed on a table in the midline of an imaginary line connecting the distal joints of thumb and index finger. The patient is asked to pinch the pen with the tips of thumb and index finger, lift it at least 2 cm (elbow remains in contact with the table), and release it.

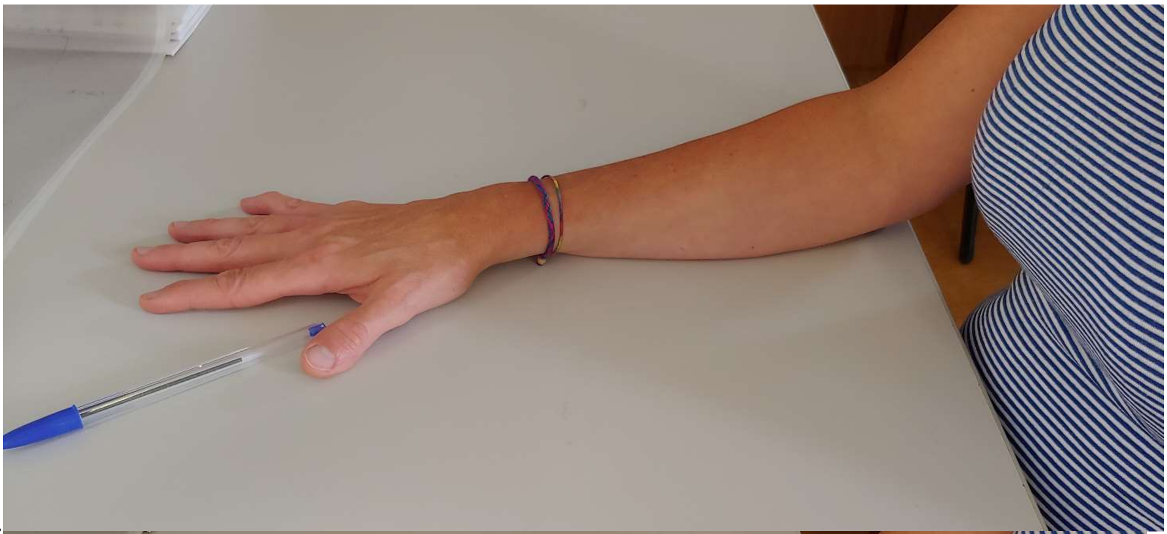
Clinical score from 0 to 3 is provided by comparing affected side with non-affected one as follows:

0 = No movement. The pinch is not possible.

1 = The movement task is not completed (less of 50% of the task). Some prehension is possible but the pinch is not sufficiently stable to lift the object; the pinch occurs with the use of the less affected hand to stabilize the object for inadequate finger opening and the release is not possible. Some fingers movement is required otherwise the score is 0

2 = The movement task is not completed (more of 50% of the task). The object is pinched and lifted but it falls or the task is completed using alternative pinching strategies (e.g. pinching with all the fingers, tripod pinch, pinching and releasing of the object is possible with abnormal orientation of fingers and wrist toward the object and the forearm is lifted off the table)

3 = The task is completed using the expected pattern (normal orientation of fingers or wrist toward the object, the pinch occurs with opposition of pads of index finger and thumb, and wrist extension).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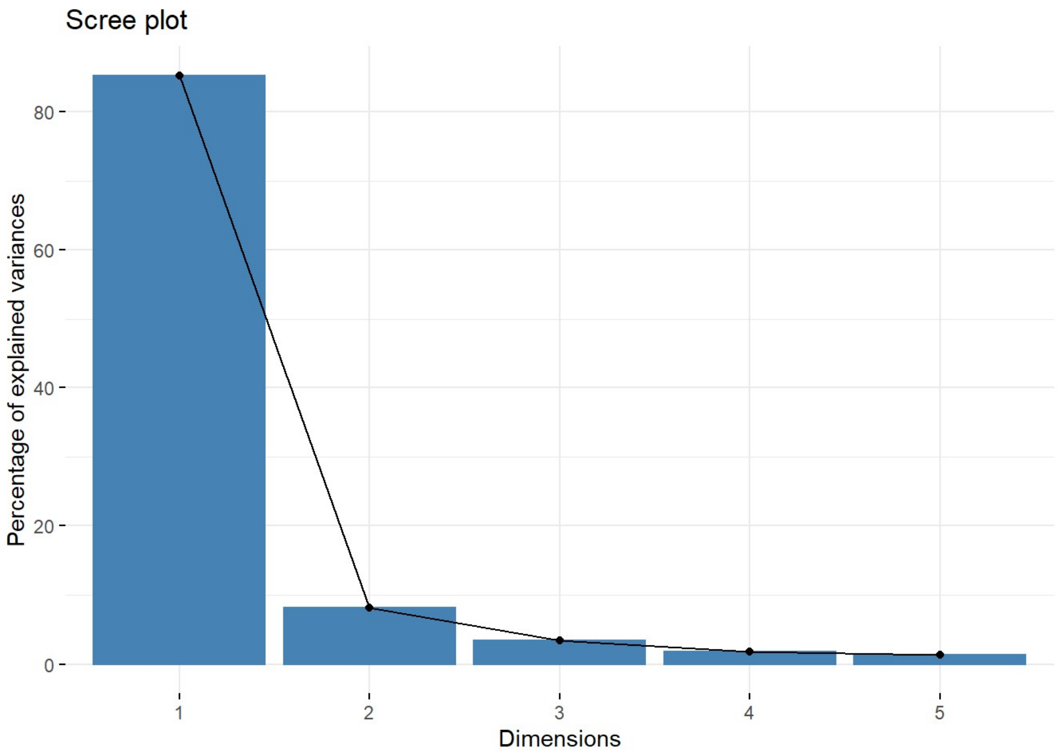
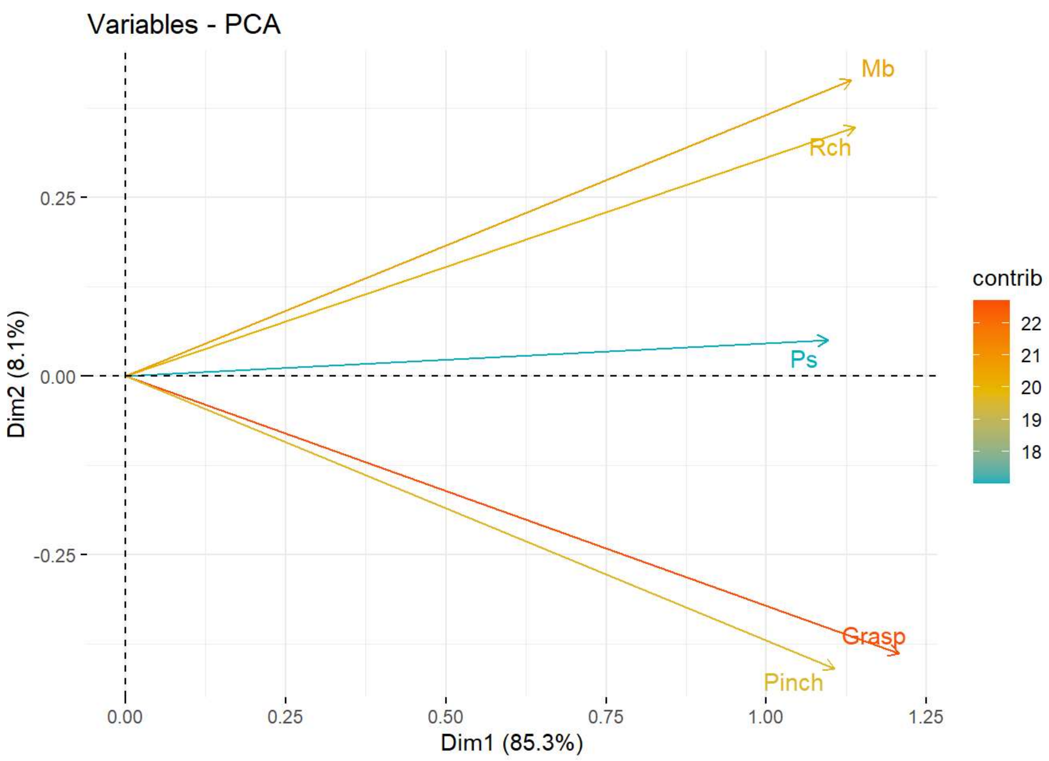
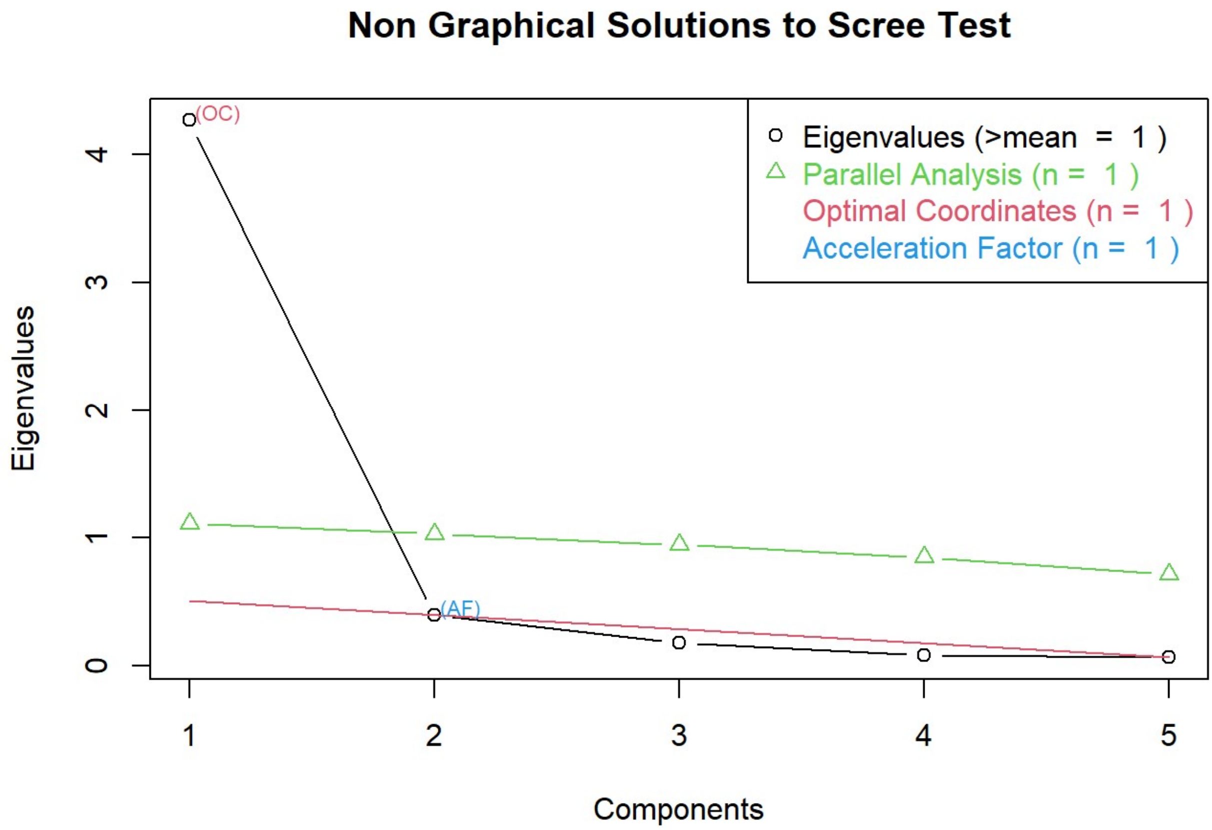
Supplementary Material 2. Scree plot and biplot from Principal Component Analysis (PCA).





The scree plot showed that the first principal component explained more than 85% of variance.



The Kaiser rule confirmed that the FAST-UL tool was unidimensional, with the first eigenvalues equal to 4.26. The FAST-UL tool was unidimensional, as also confirmed by the non-graphical solutions to the scree test through latent parallel analysis with 100 replications.

Supplementary Material 3.Item characteristics curves of the FAST-UL items.

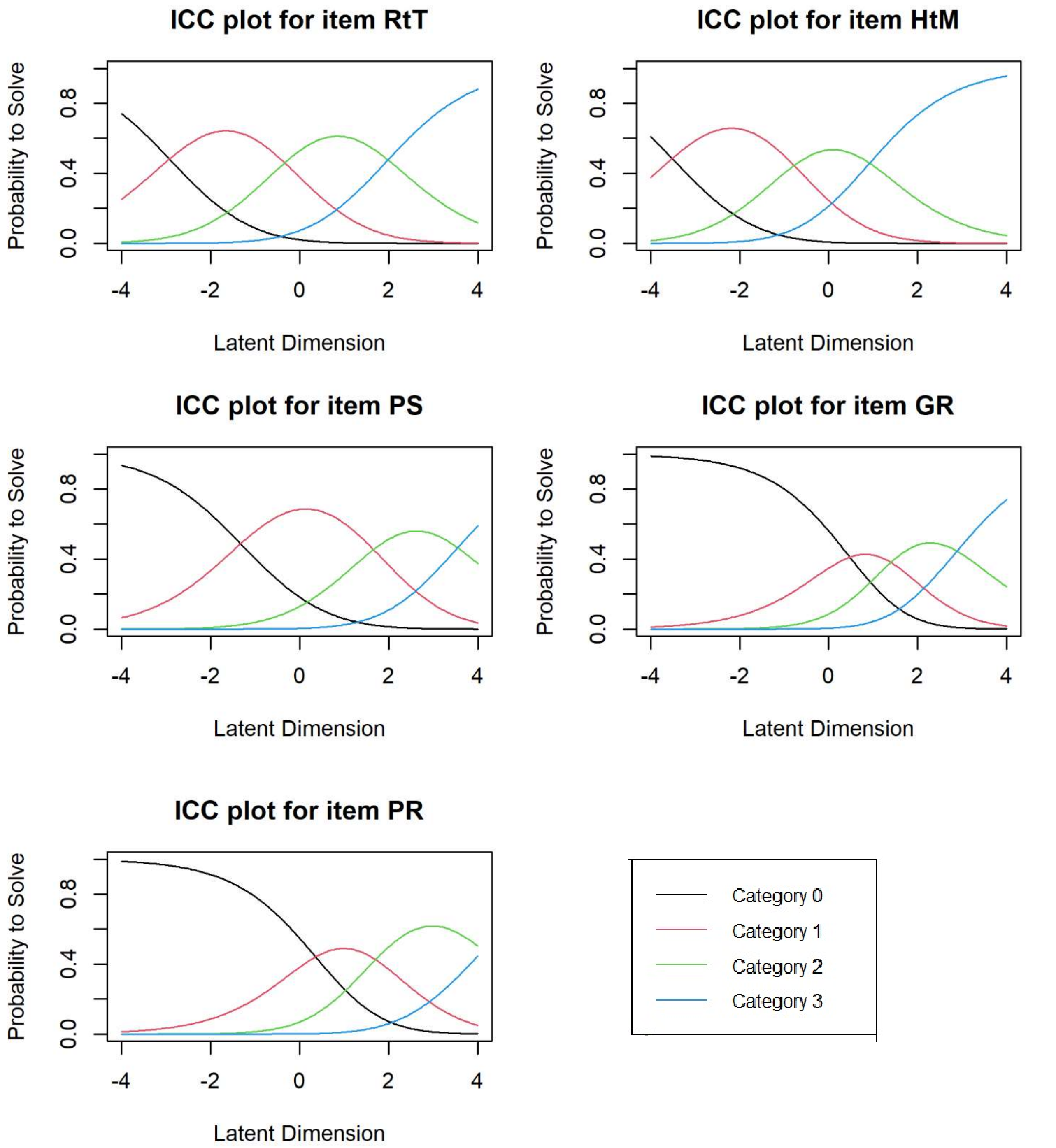


Figure footnote. Lines showed the probability to solve for category 0 (black lines), for category 1 (red lines), for category 2 (green line) and for category 3 (blue line).