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Reliability and validity of the trunk position sense and modified functional reach tests in individuals after stroke

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Abstract

ABSTRACT: The psychometric qualities of the proprioception and dynamic trunk control tests have rarely been studied in individuals after stroke.
Objective: To investigate the reliability and validity of the Trunk Position Sense Test (TPS) and Modified Functional Reach Test (MFRT) in persons after stroke.
Methods: Thirty-two participants were included. The TPS and MFRT were assessed by two physiotherapists during a first session. After resting, a second session was conducted. The intraclass correlation coefficient (ICC) was calculated to assess the test–retest ($ICC_{3,k}$) and inter-rater reliability ($ICC_{2,k}$). Pearson correlations coefficients were calculated between TPS/MFRT performances and clinical tests (trunk strength, Timed Up and Go and Balance Assessment in Sitting and Standing Positions – BASSP).
Results: The TPS inter-rater reliability was good for vertical error (ICC = 0.75 [0.50–0.88]) while it was moderate for horizontal error (ICC = 0.48 [0.10–0.75]) as well as for test–retest reliability ($0.39 \leq ICC \leq 0.59$). As for the MFRT, inter-rater ($0.76 \leq ICC \leq 0.90$) and test–retest reliability ($0.71 \leq ICC \leq 0.91$) were good to excellent for anterior, paretic et non-paretic displacements. Horizontal errors for the TPS ($-0.26 \leq r \leq -0.36$) and anterior MFRT ($0.38 \leq r \leq 0.64$) values correlated moderately with trunk strength.
Conclusion: The MFRT is a reliable test for persons after stroke with trunk control impairments. The TPS does not appear to be relevant for post-stroke individuals. This can be explained by the fact that its procedure is not easily applied for individuals after stroke – who may have significant motor and cognitive impairments.

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balance; proprioception; stroke; trunk control; trunk position sense

Introduction

In order to develop an accurate diagnosis and to be able to readjust the neuro-rehabilitation treatment plan, it is crucial to use the best clinical tests. In neurology, the factors to consider when selecting outcome measure in clinical practice are mainly the type of measure, the patient and clinical factors, the feasibility and the psychometric factors (Potter, Fulk, Salem, and Sullivan, 2011). However, many tests are used in clinical practice without the psychometric qualities being known, especially for quantitative tests on the trunk control for individuals after stroke.

The trunk control is the ability to maintain the posture of the body, to adjust weight shifting, and to perform selective movements in the trunk to maintain the center of mass within the limits of the base of support (Jung, Kim, Chung, and Hwang, 2014). Hemiparesis after stroke induces limited postural control during: sitting (Morishita et al., 2009); standing (Duclos, Maynard, Abbas, and Mesure, 2015); as well as gait impairments (Hesse et al., 1997) in a context where the sensorimotor system is disturbed (Dos Santos, Salazar, Lazarin, and Russo, 2015). Proprioceptive deficits appear to negatively influence joint stability, coordination, postural control and motor learning (Afzal, Byun, Oh, and Yoon, 2015; Dos Santos, Souza, Desloovere, and Russo, 2017). Indeed, during rehabilitation, the repetition of exercises allows progressive correction of postural adjustments through trial and error, using proprioceptive feedback. Thus, inaccurate or imprecise proprioceptive information limits the development of postural adjustments which, in turn, limits motor recovery (Yousif, Cole, Rothwell, and Diedrichsen, 2015). A systematic review has highlighted that proprioceptive training (e.g. somato-proprioceptive stimulation, positional sense, and motion detection threshold exercises)

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improves patients' motor recovery including those with neurological pathologies (Aman, Elangovan, Yeh, and Konczak, 2014). Thus, it is crucial to assess proprioception and postural control from the beginning of the rehabilitation in order to be able to offer adapted exercises early after the stroke.

Proprioceptive disorders in individuals after stroke have several causes: disruption in normal muscle tone and muscle weakness seems to induce a decreased sensitivity of sensors (Yang and Kim, 2015); the central nervous system processes the information in an abnormal way following the hemispheric lesion (Son et al., 2013); and cognitive deficits (Learman et al., 2016). Proprioception includes statesthesia (i.e. joint position sense) and kinesthesia (i.e. sensation of joint movement) (Han et al., 2016). After stroke, previous studies highlighted increased positional errors of the limbs in both sides (i.e. contralateral and ipsilateral to the damaged hemisphere) compared to age-matched controls (Lin, Hsu, and Wang, 2012; Niessen et al., 2008; Son et al., 2013; Yalcin et al., 2012). In contrast, kinesthesia (i.e. motion detection threshold) is difficult to assess because it requires complex mechanical tools (Niessen et al., 2009). While a systematic review has shown the importance of trunk control deficits after stroke (Van Criekinge et al., 2019), only four studies have tested trunk position sense in individuals after stroke (Jung, Kim, Chung, and Hwang, 2014; Learman et al., 2016; Oh and Choi, 2017; Ryerson et al., 2008). Compared to healthy subjects, individuals with hemiparesis have increased trunk positional errors in the acute (Learman et al., 2016) and chronic phases (Ryerson et al., 2008). These deficits may correlate with increased postural control disorders and risk of falls (Ryerson et al., 2008). The trunk position sense capacities seem to improve after motor imagery training (Oh and Choi, 2017) or exercises with body transfers in sitting position (Jung, Kim, Chung, and Hwang, 2014). Learman et al. (2016), using an electromagnetic tracking tool, showed a moderate to good intra-day reliability of the trunk position sense in individuals after stroke in acute phase. However, inter-rater reliability was not tested and this tool is not widely available in clinical practice. Previously, for healthy subjects and individuals with low back pain, a simple clinical tests of the trunk position sense had shown good reliability (Enoch et al., 2011; Petersen et al., 2008). It would therefore be interesting to test the reliability of a simple clinical test of the trunk position sense in stroke context.

Assessing seated postural control is crucial after stroke because this deficit negatively influences: standing balance (van Nes Ij, Nienhuis, Latour, and Geurts, 2008); walking (Van Criekinge et al., 2019); upper limbs motor function (Lee, Shin, and Song, 2016); and functional recovery (Duarte et al., 2002). Deficits in trunk control may be associated with trunk muscle weakness (Karthikbabu and Verheyden, 2021) and proprioceptive impairments (Ryerson et al., 2008). Studies of test reliability in patients after stroke are more numerous for standing than sitting balance position with a predominance of qualitative tests and scales (Bruyneel, 2017). In sitting position, a previous study of the Modified Functional Reach Test (MFRT) showed moderate-to-excellent intra-session reliability in ten individuals after stroke (Katz-Leurer et al., 2009) without testing test-retest and inter-rater reliability. The MFRT assesses dynamic sitting balance by dissociating the paretic and non-paretic sides displacements, and has the advantage of being simple and quick to perform in clinical practice. Our objective was to assess the reliability (i.e. test-retest and inter-rater) and the validity of a trunk position sense (TPS) and MFRT tests for individuals with post-stroke hemiparesis in subacute phase. Our hypothesis was that both tests have intra-class correlation coefficient (ICC) greater than 0.75 which makes them suitable for use in clinical practice (Portney and Watkins, 2009). Nevertheless, the MFRT, which seems to be less sensitive to cognitive deficits, should be more reliable than the TPS. For construct validity the TPS and MFRT tests should be related to trunk strength and Timed Up and Go tests (TUG) that assess balance and functional mobility (Jung, Kim, Chung, and Hwang, 2014).

Methods

Participants

The target population was individuals after stroke with hemiparesis aged 50 to 75. This age category represents the typology of patients that is present in neurorehabilitation services. The upper limit of 75 years of age was applied to limit bias related to the age of the patients (i.e. cognitive and motor) while preserving the possibility of including enough participants. To be included, individuals had to have had a single stroke episode in the 3 months prior to their recruitment (i.e. subacute phase) and to be medically stable. The choice of the subacute phase is justified by the potential for motor recovery, which is the highest in this phase and which requires an accurate assessment of trunk capacity disorders (Bernhardt et al., 2017). In order to ensure that the test instructions were well-understood, individuals had to have a Mini-Mental State Examination (MMSE) score higher than 22 (Learman et al., 2016). In addition, they had to be able to sit for 30 seconds independently in order to perform the TPS and MFRT tests (Jung, Kim, Chung, and Hwang, 2014). Individuals were excluded if they had other pathologies affecting balance, spinal pathologies or trunk pain, medical complications, and if they had major impairments in understanding the tests.

All individuals were recruited in the neuro-rehabilitation department of the Geneva University Hospitals. Potentially eligible patients were informed orally, and after a reflection period of at least 24 hours, they were given a written and oral explanation before signing the consent form. To encourage free consent, a person independent from the department carried out this step. This study was approved by the cantonal research ethics committees (CCER Geneva – 2018-02026). The study was registered (ClinicalTrials.gov Identifier: NCT04639453).

Raters

To participate in the study, raters had to be a physiotherapist with more than 5 years of experience in neurology. All raters were recruited from the neuro-rehabilitation department of the Geneva University Hospitals.

Procedure

First, a physiotherapist (rater 1) tested each volunteer's clinical status using : the Balance Assessment in Sitting and Standing Positions test (BASSP) (Huang et al., 2016); the maximal isometric force value of the trunk (MiFV) (Karthikbabu and Chakrapani, 2017); and the TUG test (Chan, Si Tou, Tse, and Ng, 2017).

After this first step, two physiotherapists (rater 1 and rater 2) tested the 32 individuals with stroke in one session in a random order to investigate inter-rater reliability. After resting for 2–4 hours, a second session was conducted by rater 1 to assess test–retest reliability. Raters were blinded to the data collected by the other rater.

Clinical tests

The BASSP test contains four tests: static sitting balance, static standing balance, dynamic sitting balance and dynamic standing balance (Huang et al., 2016). The first static assessment consisted in testing the postural reactions of individuals during an external push in four directions (i.e. front, back, left, and right). The static items were rated on a 5-point scale (0 = subject needed an external support; to 4 = subject was stable without aid). For dynamic assessment, three objects were placed on the floor (i.e. front/left, front, and front/right) and the subject had to pick them up. The dynamic items were rated on a 4-point scale (0 = no possibility to pick up the objects; to 3 = objects picked up without external aid). The total scores ranged from 0 to 14. The reliability of the BASSP test is excellent for individuals after a stroke (Huang et al., 2016).

Trunk strength was tested in isometric condition with the hand-held dynamometer (MicroFET® 2, Biometrics). This tool, used for the trunk MiFV assessment, is reliable for individuals after stroke (Karthikbabu and Chakrapani, 2017). The patient was in a stable sitting position with feet support. The dynamometer was placed on the lateral part of the trunk: the sub-axillary zone to test the paretic side and then the non-paretic side; on the sternum (flexion); and on the T4 vertebra (extension). The individual pushed against the dynamometer for 5 seconds and the MiFV was recorded (N). The rater stabilized his upper limb in the axis of the dynamometer, against the wall. Two trials were performed with a 30 seconds rest between each trial.

The TUG test was used for assessing functional mobility and dynamic postural control (Chan, Si Tou, Tse, and Ng, 2017). A cone was placed in front of a chair, 3 m away. The TUG test measures the time (s) taken for an individual to rise from the chair, walk 3 m, half turn around the cone, walk back to the chair, and sit back down. This test showed a good reliability in individuals with hemiparesis after stroke (Chan, Si Tou, Tse, and Ng, 2017).

Trunk Position Sense Test (TPS)

The TPS test was performed in sitting position to assess how accurately the subject could re-position his trunk to the initial trunk position, after the trunk had been actively displaced. Test procedure was based on a TPS test reliability study conducted in individuals with low back pain (Enoch et al., 2011) and on studies testing the TPS in post-stroke context (Jung, Kim, Chung, and Hwang, 2014; Learman et al., 2016; Ryerson et al., 2008). Participants were in a stable sitting position on a stool with their feet on the floor. The patients' eyes were closed to avoid visual feedback. The rater guided them into the target trunk position (i.e. 30° flexion checked with the inclinometer). Behind patients, an electric table was positioned to adjust the laser pointer on the T12 vertebra (i.e. anatomical landmark marked with a cross). Individuals were instructed to remember this target position, and then to rotate twice for both the

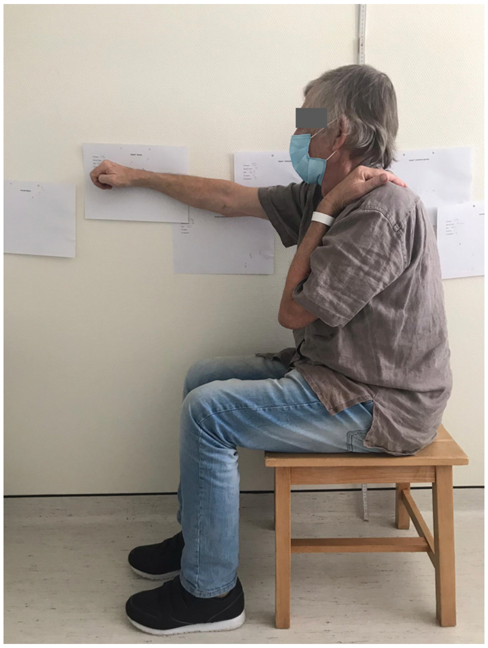

Figure 1. Modified functional reach setting test for anterior movement.

paretic and non-paretic side and then return to the target position. The divergence between laser projection and center of the cross was measured vertically and horizontally. Patients did one training test followed by three successive real trials.

Modified Functional Reach Test (MFRT)

The MFRT was performed following the procedure described in the study by Katz-Leurer et al. (2009). The participant was in a sitting position on a stool, feet flat on the floor, hips and knees at 90° flexion with the non-paretic side of the wall. The non-paretic shoulder was in 90° flexion, elbow extended and fist closed (Figure 1). The position of the metacarpophalangeal joint was marked on the wall (marker 1). The participant bent forward as far as possible with the arm horizontal while maintaining balance. The metacarpophalangeal joint marker was then noted in this new position (marker 2). The distance between the two landmarks was then recorded.

Then, participants were seated with their back to the wall with upper limbs relaxed. The location of the acromion was noted (marker 1) before individuals leaned as far as possible toward the non-paretic or paretic side by tilting the trunk without destabilizing the pelvis. In this final position, the position of the acromion was noted (marker 2) and the horizontal distance from marker 1 was measured. Individuals performed two training trials before taking three successive measurements in each direction (i.e. anterior, paretic, and non-paretic).

Statistical analysis

Sample size calculation

Sample size calculation used the method of Walter, Eliasziw, and Donner (1998) based on an: acceptable ICC = 0.75 (i.e. threshold for use in clinical practice) (Portney and Watkins, 2009); expected ICC = 0.85 based on ICCs obtained in healthy subjects for the TPS (Enoch et al., 2011); and a power at 80% and a significance of p = .05. A sample size of 32 participants was necessary.

Data processing

For MiFV of the trunk, data processing consisted of normalizing the data with the subject's weight according to the following formula:

$$MiFVnormalized = \frac{\mathrm{Mesuredvalue(N)}}{\mathrm{Weight(kg)}} x100$$

The values of the MFRT were normalized with the participant's height:

$$MFRTnormalized = \frac{\mathrm{Mesuredvalue(cm)}}{\mathrm{Height(cm)}} x100$$

The different trials were averaged for each test ($\mathrm{MFRT}_{\mathrm{normalized}}$ and TPS), for each session (session 1 and session 2) and for each rater (rater 1 and rater 2).

Descriptive statistics

We used descriptive statistics to analyze the demographic variables and the performance of each test. Descriptive statistics consisted of calculating means and standard deviations for quantitative variables, and frequencies for qualitative variables (e.g. gender and stroke side).

Reliability

Inter-rater reliability was assessed by the agreement of data between rater 1 and rater 2 tested by the $\mathrm{ICC}_{(2,k)}$ model (Koo and Li, 2016). To assess the test–retest reliability (i.e. agreement of data between session 1 and 2), the $\mathrm{ICC}_{(3,k)}$ model was applied. An ICC value: below 0.40 was considered poor; between 0.40 and 0.59 moderate; between 0.60 and 0.74 good; and from 0.75 excellent (Cicchetti, 1994). To assess the errors in terms of units of measurement, if the ICC was greater than or equal to 0.60, the standard error of measurement (SEM – unit of measurement) was calculated according to this formula (Weir, 2005): $SEM = SD * \sqrt{(1 - ICC}$. SD is the standard deviation of the values obtained for all participants for both raters or both sessions. The minimal detectable change ($\mathrm{MDC}_{95\%}$) was calculated as follows: $MDC = SEM * 1.96 * \sqrt{2}$.

Absolute reliability was investigated using Bland Altman analysis to determine between-session agreement. The 95% limits of agreement (LOA95%) represent two standard deviations (SD) above and below the mean difference (bias) between sessions.

Construct validity

To assess validity, Pearson correlation coefficients (*r*) were calculated between target tests ($MFRT_{normalized}$; TPS) and with clinical tests: $MiFV_{normalized}$, BASS and TUG. Results were considered statistically significant when the *p* value was less than 0.05. A correlation between two tests on the same capacities should fall within the range of 0.4–0.8 (Streiner and Norman, 2008). A lower correlation suggests either that the reliability of one of the tests is low, or that they are measuring different phenomena. A correlation higher than 0.8 suggests that both tests might be interchangeable to assess patients in clinical practice. Statistics were performed using SPSS software (SPSS Inc., Chicago, IL, USA).

Results

Thirty-two individuals with hemiparesis after stroke were included in this study (9 women and 23 men, age: 60.93 ± 9.51 years, height: 1.73 ± 0.09 m, weight: 75.17 ± 13.87 kg, body mass index: 24.98 ± 3.28 kg/m^2). The mean duration since the stroke event (12 hemorrhagic and 20 ischemic) was 55.64 ± 26.56 days. A majority of hemiparesis cases concerned the left side (22 vs. 10 for the right side). The mean MMSE score was 25.62 ± 2.67/30 points. The results of BASSP, $MiFV_{normalized}$, and TUG are described in Table 1. Three physiotherapists carried out the tests (age between 30 and 45 years, 2 women and 1 man, > 5 years' experience in neuro-rehabilitation).

Table 1. Clinical characteristics of included participants (mean ± standard deviation).

Clinical tests	N = 32
Balance assessment in sitting and standing position (BASSP) (/14 points)	12.20 ± 3.15
Trunk strength (%)	32.29 ± 11.21
- Paretic side	32.11 ± 8.31
- Non-paretic side	36.50 ± 11.77
- Anterior	47.81 ± 12.09
- Posterior	
Timed Up and Go test (s)	17.86 ± 14.78

Feasibility of the tests

All 32 participants successfully completed both TPS and MFRT tests without adverse events.

Reliability for the TPS

The inter-rater reliability was excellent for vertical error measurement ($ICC_{2,k}$ = $0.75_{[0.50–0.88]}$, SEM = 0.40 cm and MDC = 1.12 cm) (Table 2).

Bland Altman analysis highlighted a bias between the two raters of −0.28 cm with a LOA95% at 1.44 cm (Figure 2).

When the horizontal error measurement was collected, inter-rater reliability was moderate ($ICC_{2,k}$ = $0.48_{[0.10–0.75]}$). Concordance between session 1 and 2 for rater 1 (test–retest reliability) showed moderate reliability for horizontal error ($ICC_{3,k}$ = $0.59_{[0.12–0.79]}$) and poor reliability for vertical error measurement ($ICC_{3,k}$ = $0.39_{[0.22–0.70]}$) (Table 2).

Reliability for the $MFRT_{normalized}$

All $MFRT_{normalized}$ directions highlighted ICC values above 0.75, except for test–retest reliability in non-paretic side displacement (Table 3). Inter-rater reliability was excellent for movements in the anterior, paretic and non-paretic directions (0.76 ≤ $ICC_{2,k}$ ≤ 0.90). SEM values ranged from 1.25% to 1.57%. For anterior direction, the mean differences between raters were low (bias = 0.84%) and the LOA95% = 5.79% (Figure 3).

Test–retest reliability for non-paretic movements was lower ($ICC_{3,k}$ = 0.71 [0.41–0.86]) than paretic ($ICC_{3,k}$ = 0.84 [0.68–0.92]) and anterior measures ($ICC_{3,k}$ = 0.91 [0.78–0.96]) (Table 3). SEM values ranged from 1.14% to 1.51%. The mean difference between sessions was 1.37% for anterior movements (LOA95% = 5.33%) and 0.47% for paretic side (LOA95% = 4.19%) (Figures 4 and 5).

Table 2. Inter and intra-rater reliability for the trunk position sense test.

	Session 1		Session 2	Inter-rater reliability		Test-retest reliability	
Parameters	Rater 1 (mean ± SD)	Rater 2 (mean ± SD)	Rater 1 (mean ± SD)	ICC 2,k (CI95%)	SEM; $MDC_{95\%}$ (cm)	ICC 3,k (CI95%)	SEM; $MDC_{95\%}$ (cm)
Vertical Error (cm)	0.96 ± 0.79	1.14 ± 0.84	0.78 ± 0.58	**0.75 [0.50–0.88]**	0.40; 1.12	0.39 [0.22–0.70]	NA
Horizontal error (cm)	0.43 ± 0.33	0.43 ± 0.44	0.39 ± 0.27	0.48 [0.10–0.75]	NA	0.59 [0.12–0.79]	NA

ML = mediolateral, AP = anteroposterieur, NA = non applicable, ICC = Intraclass Correlation Coefficient, SEM = Standard Error Measurement, MDC = Minimal Detectable Change, CI = Confidence Interval

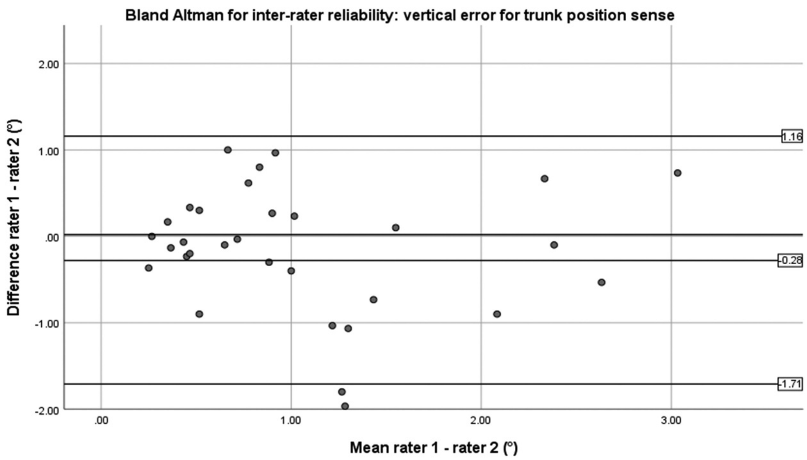

Figure 2. Bland and Altman plot for inter-rater reliability of the trunk position sense test (vertical error). Bias = −0.28 cm, CI95% = 1.44 cm.

Table 3. Intra and inter-rater reliability for the modified functional reach test (normalized values).

	Session 1		Session 2	Inter-rater reliability		Test-retest reliability	
Parameters	Rater 1 (mean ± SD)	Rater 2 (mean ± SD)	Rater 1 (mean ± SD)	ICC 2,k (CI95%)	SEM; $MDC_{95\%}$ (%)	ICC 3,k (CI95%)	SEM; $MDC_{95\%}$ (%)
Anterior displacement (%)	19.63 ± 5.21	18.79 ± 4.74	18.26 ± 4.85	**0.90 [0.80–0.95]**	1.57; 4.34	**0.91 [0.78–0.96]**	1.51; 4.18
Paretic side displacement (%)	10.28 ± 2.96	9.67 ± 2.68	9.75 ± 2.74	**0.76 [0.51–0.88]**	1.38; 3.82	**0.84 [0.68–0.92]**	1.14; 3.14
Non-paretic side displacement (%)	10.14 ± 2.69	9.75 ± 2.55	9.09 ± 2.64	**0.77 [0.53–0.89]**	1.25; 3.46	0.71 [0.41–0.86]	1.45; 4.02

ICC = Intraclass Correlation Coefficient, SEM = Standard Error Measurement, MDC = Minimal Detectable Change, CI = Confidence Interval

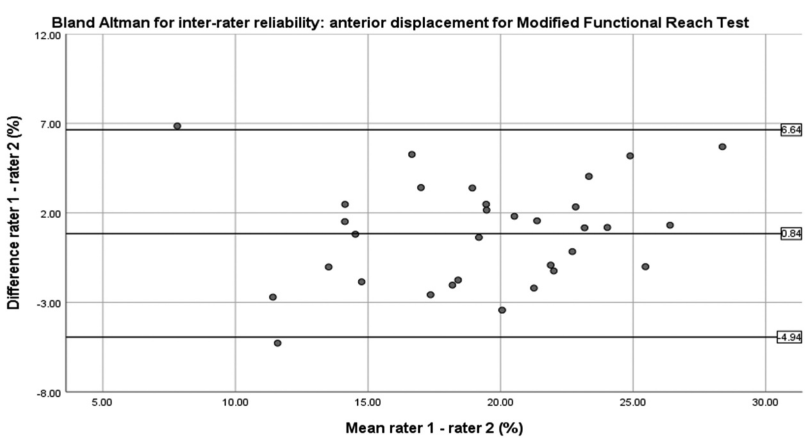

Figure 3. Bland and Altman plot for inter-rater reliability of the modified functional reach test (anterior movement). Bias = 0.84%, CI95% = 4.19%.

Construct validity

Table 4 describes the correlations between $MFRT_{normalized}$ and TPS values and the following clinical tests: BASSP, $MiFV_{normalized}$ and TUG. A non-significant correlation was observed with the BASSP. The horizontal error of the TPS was significantly correlated with the non-paretic and posterior $MiFV_{normalized}$ ($r = -0.36$, $p = .042$), and with TUG performance ($r = 0.50$, $p = .004$). For $MFRT_{normalized}$ values, only the forward measures were significantly related to the $MiFV_{normalized}$ values ($0.38 \le r \le 0.64$, $p < .030$).

Discussion

This study investigated the reliability (test-retest and inter-rater) and the validity of the TPS and $MFRT_{normalized}$ for individuals with post-stroke

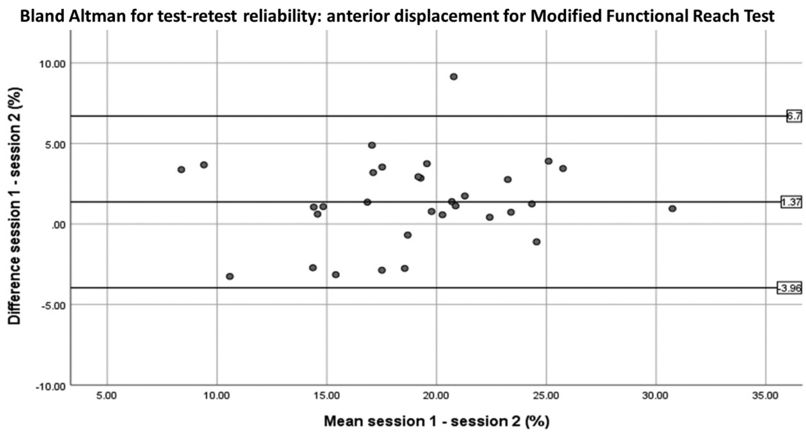

Figure 4. Bland and Altman plot for test-retest reliability of the modified functional reach test (anterior movement). Bias = 1.37%, CI95% = 5.33%.

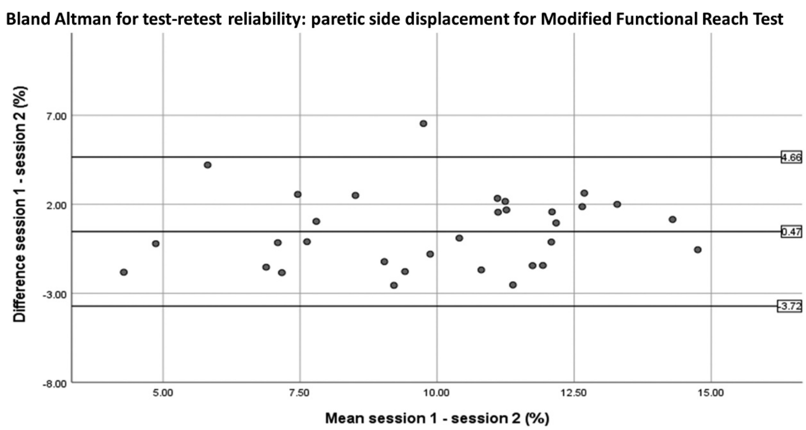

Figure 5. Bland and Altman plot for test-retest reliability of the modified functional reach test (paretic movement). Bias = 0.47%, CI95% = 5.79%.

Table 4. Pearson correlation coefficients between tests and p value.

		MFRT				Trunk isometric strength test				
		Anterior	Paretic side	Non-paretic side	BASSP	Paretic side	Non-paretic side	Anterior	Posterior	TUG
Trunk Position Sense test	Vertical	−0.09 (NS)	−0.19 (NS)	−0.16 (NS)	−0.08 (NS)	−0.13 (NS)	−0.12 (NS)	−0.03 (NS)	−0.15 (NS)	−0.01 (NS)
	Horizontal	−0.04 (NS)	−0.13 (NS)	−0.20 (NS)	−0.33 (NS)	−0.26 (NS)	***−0.36 (0.044)***	−0.28 (NS)	***−0.36 (0.042)***	***0.50 (0.004)***
MFRT	Anterior	NA	NA	NA	0.03 (NS)	***0.64 (<0.001)***	***0.42 (0.018)***	***0.38 (0.030)***	***0.40 (0.024)***	−0.21 (NS)
	Paretic side	NA	NA	NA	0.26 (NS)	0.33 (NS)	0.21 (NS)	0.12 (NS)	0.12 (NS)	−0.20 (NS)
	Non-paretic side	NA	NA	NA	0.17 (NS)	0.26 (NS)	0.24 (NS)	0.09 (NS)	0.19 (NS)	−0.33 (NS)

MFRT = Modified Functional Reach Test, BASSP = Balance Assessment in Sitting and Standing Positions, TUG = Timed Up and Go Test, NS = Non significant ($p > 0.05$), NA = Non applicable.

hemiparesis. The results partially confirmed our hypotheses. For the TPS, only the inter-rater reliability of the vertical positional error was higher than ICC = 0.75, while reliability was good to excellent for all values of $MFRT_{normalized}$. Test performances were partially associated with $MiFV_{normalized}$ of the trunk and TUG. These contrasting results highlighted the importance of assessing the psychometric qualities of the tests for individuals with stroke before using them in research and clinical practice.

Trunk Position Sense Test (TPS)

The results of the TPS highlighted low inter-rater and test–retest reliability as well as high SEM (MDC). For this simple clinical test with a laser tool, test–retest reliability was lower than the results of Learman et al. (2016) who used an electromagnetic device. Since the positional error is usually less than 4 cm with very small deviations, the tool's accuracy could influence quality of measurements. Nevertheless, the reliability of the TPS test with simple clinical measurements appears to be excellent in healthy subjects and individuals with low back pain (Enoch et al., 2011; Petersen et al., 2008). Factors that may influence the quality of the test are mainly the tool used, but also the method. Previously, Goble (2010) observed in healthy subjects divergent results of the joint positional sense test depending on the testing method. Positional errors are less important when the ipsilateral limb is repositioned than when the instruction was given with the contralateral limb. For the TPS, only the ipsilateral repositioning method is applicable. The positional error is therefore influenced by proprioception, the disruption in muscle tone, muscle weakness (Yang and Kim, 2015), but also by concentration and memory (Goble, 2010). Thus, in individuals after stroke, cognitive disorders can have an impact on the quality of the patient's performance during the test, which would explain the lower reliability observed in comparison with subjects without cognitive disorders (Enoch et al., 2011). When performing the TPS, it is therefore essential to assess patients' cognitive status to ensure that it is trunk proprioception that is being measured and not memory capacity.

Inter-rater reliability was greater than 0.75 for vertical error. Horizontal error was also recorded, whereas this is not usually the case in other trunk position sense tests (Jung, Kim, Chung, and Hwang, 2014; Learman et al., 2016; Oh and Choi, 2017). A previous study in individuals after stroke in chronic phase suggested distinguishing betweenvertical and horizontal errors (Ryerson et al., 2008). The authors observed that horizontal error correlates with the Berg Balance Scale and the Postural Assessment Scale for Stroke, which was not the case for vertical error. Our results seem to confirm that only horizontal error may correlate with $MiFV_{normalized}$. However, the reliability of the TPS seems too low to be conclusive and to use this parameter with individuals after stroke.

Modified Functional Reach Test ($MFRT_{normalized}$)

Test-retest and inter-rater reliability were sufficient to use $MFRT_{normalized}$ in all three directions of trunk movement for individuals after stroke in sub-acute phase, except for non-paretic side displacement for test–retest reliability. For the same population, Katz-Leurer et al. (2009) observed higher reliability than our results. They tested the concordance of the results between two successive trials during the same session, whereas we tested two sessions separated by a rest of 2 h to 4 h. This time interval between the two sessions was intended to avoid a memorization bias for the rater and to verify the stability of the test when it is performed twice by the same person on the same participants. For test–retest reliability, the appropriate rest period seems to be 1 day maximum in the subacute stroke phase (Gray, Ivanova, and Garland, 2014) and seven days in chronic phase (Gasq et al., 2014). However, when tests are performed on the same day, it is not possible to rule out that daily activities in the rehabilitation center and the tests of the study (duration 1h30) impact the test's quality in comparison with immediate reevaluation.

When assessing test–retest reliability, displacement measurement on the paretic side was more reliable than on the non-paretic side, which corroborates the results of Katz-Leurer et al. (2009) on MFRT and the reliability results obtained during the evaluation of the joint positional sense of the hand (Rinderknecht et al., 2018). One possible hypothesis may be that data on the non-paretic side are more homogeneous than on the paretic side, which would weaken the ICC. Nevertheless, in our study, results between two sides were very close and the reliability remains sufficient for both sides.

The MDC values highlight that a change between two measurements greater than 5% is required to be sure that the change in performance is related to a change in the patient.

The results of the construct validity suggest that there is a moderate relationship between the ability to move the trunk forward and $MiFV_{normalized}$. These results seem to confirm the link between trunk muscle strength and trunk control abilities after stroke (Karthikbabu and Verheyden, 2021); and the influence of abdominal strength training on the increase in forward movement during the functional reach test (Lee et al., 2020).

Limitations

For the TPS and $MFRT_{normalized}$ to be relevant for individuals after stroke, certain abilities are required: autonomous sitting during 30 seconds and MMSE > 22 (Katz-Leurer et al., 2009). Therefore, the results are not transposable to individuals with stroke in case of severe deficits. All subjects completed the entire test session. Nevertheless, despite strict eligibility criteria, some participants had difficulties in performing the tests, mainly due to fatigue or difficulty in understanding the instructions. This affected four of the 32 participants included. In case of failure of doubt about the quality of the test, the trial was repeated. For the TPS, the values were better in the second session. Given that the test conditions were the same, it is likely that a learning effect influenced performance despite the first trial not being taken into consideration for the results. Raters were blinded to the other rater's measurements, but not to their own measurements. This methodological choice was made in order to respect the usual conditions of testing in clinical practice. To limit the risk of bias, the raters had homogeneous characteristics and were specialists in neuro-rehabilitation.

Conclusion

Reliability and validity of trunk tests is variable, depending on the evaluated test and the target population. In individuals after stroke, the reliability of the TPS seems too low to be conclusive and to use this parameter with individuals after stroke in clinical practice and research. In contrast, the $MFRT_{normalized}$ demonstrated a good to excellent test-retest and inter-rater reliability. Construct validity analysis revealed a moderate correlation of MFRT anterior displacement with the trunk muscle strength. This test may be used as a screening test for sitting postural control taken into account the limitations with the validity.

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