NeuroRehabilitation 38 (2016) 359–370
DOI:10.3233/NRE-161327
IOS Press

Scapulohumeral control after stroke: A preliminary study of the test-retest reliability and discriminative validity of a clinical scapular protocol (ClinScaP)

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Abstract.
BACKGROUND: Clinical scapulohumeral tests are lacking post-stroke.
OBJECTIVE: To test reliability and discriminant validity of clinical scapulohumeral assessments post-stroke.
METHODS: Following tests were assessed in 57 individuals with stroke (IwS) (subdivided in a low, moderate, high proximal arm function (PAF) group) and 15 healthy controls: (1) Observation of tilting/winging; (2) shoulder girdle position tests (pectoralis minor index, acromial index, scapular distance test); (3) scapular lateral rotation measurement; (4) maximal humeral elevation and (5) medial rotation test were executed. 15 IwS were measured twice by the same assessor to determine test-retest reliability. Differences between controls and IwS and between IwS with different levels of PAF were assessed.
RESULTS: ICCs were very high for all tests (>0.80), except the pectoralis minor index (0.66). Weighted Kappas were high for observation and the medial rotation test (>0.70). Group differences were found for observation, lateral rotation and humeral elevation. IwS compared to controls, and IwS with lower compared to higher PAF generally showed increased lateral rotation ($p < .01$); decreased maximal active humeral elevation ($p < .001$); and more often tilting and winging ($p < .05$).
CONCLUSIONS: The use of these tests in clinical settings will allow for identification of altered scapular characteristics, which will enhance treatment planning for PAF post-stroke.

Keywords: Scapula, movement patterns, clinical test, stroke

1. Introduction

The brain damage underlying a stroke results in several motor impairments such as muscle weakness, increased muscle tone, pathological muscle synergies and altered temporal muscle activity (De Baets, Jaspers, Janssens, & Van Deun, 2014; Frontera, Grimby, & Larsson, 1997; Grimby, Hannerz, & Ranlund, 1974; McComas, Sica, Upton, & Aguilera, 1973). At the level of the shoulder complex, these motor impairments might specifically hamper scapulohumeral control, i.e. the adaptation of scapular position and movement according to the humeral position. Reduced scapulohumeral control is known to contribute to the difficulties individuals with stroke (IwS) experience when moving their paretic arm (Rundquist, Dumit, Hartley, Schultz, & Finley, 2012).

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Upper limb rehabilitation after stroke could benefit from specific training to enhance scapular positioning and scapulohumeral movement control. However, such therapy firstly requires an extensive evaluation of the scapulothoracic joint.

Within the area of musculoskeletal research, there is a wide availability of tests or measurements to assess scapular position and scapulohumeral control in rest or during movement (Lluch et al., 2014; Struyf, Meeus, et al., 2014; Struyf, Nijs, et al., 2014). The reliability of these assessments has been verified (Lluch et al., 2014; Struyf, Meeus, et al., 2014; Struyf et al., 2009), and they are commonly used in cross-sectional or comparative studies and even in interventional research (Struyf et al., 2011; Struyf et al., 2013). Such a clinical measurement approach, covering different aspects of static and dynamic scapulohumeral control, might prove valuable to assess the role of the scapula in upper limb and shoulder (dys)function in IwS. However, clinical scapulohumeral assessments have thus far been limited to the healthy population or to persons with musculoskeletal pathologies only.

Assessment of scapulohumeral control in IwS requires a clinical protocol that offers specific scapular information, which is not covered with currently available clinical measurement scales for the upper limb after stroke. Therefore, this study introduces a clinical scapular protocol (ClinScaP), in which tests are selected based on knowledge from musculoskeletal rehabilitation. Those tests that are expected to be associated with a specific scapular rotation (i.e. protraction, lateral rotation, tilting) are retained. As such, clinical observation of tilting and winging in rest and during movement is chosen to assess three-dimensional scapular protraction and tilting (Kibler & Sciascia, 2010; Nijs, Roussel, Vermeulen, & Souvereyns, 2005; Struyf et al., 2009; Struyf et al., 2011; Struyf et al., 2013); these scapular rotations are further assessed with the scapular distance test, the pectoralis minor index and the acromial index (Borstad & Ludewig, 2005; DiVeta, Walker, & Skibinski, 1990; Nijs et al., 2005; Struyf, Meeus, et al., 2014). Scapular lateral rotation is assessed based on inclinometry at different forward flexion heights (Watson, Balster, Finch, & Dalziel, 2005). Dynamic scapulohumeral control is assessed based on maximal active humeral elevation and the medial rotation test (Lluch et al., 2014; Morrissey, Morrissey, Driver, King, & Woledge, 2008). However, prior to clinical implementation of any new protocol, its reliability and ability to discriminate between groups should be established. Therefore, this study first assesses the protocol's test-retest reliability. We furthermore hypothesize that the battery of tests is able to differentiate between (1) IwS and healthy controls; and (2) IwS with different levels of proximal arm function (PAF).

2. Methods

2.1. Participants

A convenient sample of IwS was recruited via therapists from three rehabilitation centers (Belgium). IwS were eligible for participation when they (1) had a first time stroke (cortical or subcortical area, verified using MRI); (2) could sit independently with low back support only; and (3) could perform 45° of active and 90° of passive humerothoracic forward flexion. Healthy controls were recruited via family and colleagues. Exclusion criteria for all participants were: (1) inability to understand the instructions; (2) anterolateral shoulder pain during daily activities with a painful arc between 60 and 120° of arm forward flexion for at least four weeks; (3) a positive Neer impingement test, i.e. reported pain when the humeral greater tuberosity was impacted against the inferior acromion (Neer & Foster, 1980); (4) an event of shoulder dislocation, fracture or surgery during lifetime; or (5) other systemic and/or neurologic diseases.

IwS were divided in three groups based on their score on the shoulder and elbow parts of the upper limb motor part of the Fugl-Meyer (FM elbow-shoulder, max score 36)(Platz et al., 2005), i.e. low (score ≤ 16), moderate (score 17–26) or high (score 27–36) PAF. Similar to Lum et al. (2003), these criteria were based on the observed scores in our IwS group, i.e. scores ranged between 6 and 36 (Lum, Burgar, & Shor, 2003) and this range was divided into even thirds to achieve three distinct groups.

Written informed consent, approved by the Ethical Committee of the University Hospital Leuven and the local ethical committees of each rehabilitation center, was obtained from all participants prior to participation.

2.2. Clinical scapular protocol

One skilled physiotherapist (seven years of experience in manual therapy) performed the Fugl-Meyer scale and all measures of the clinical scapular

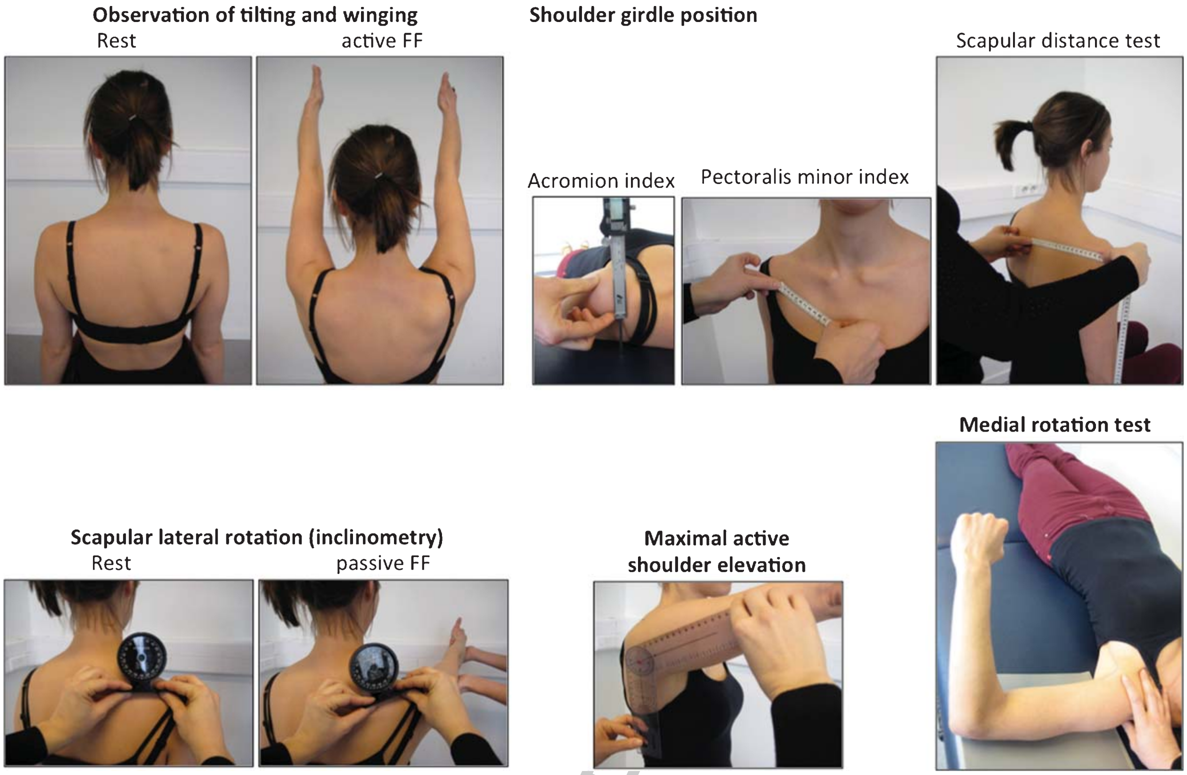


Fig. 1. ClinScaP.

protocol (ClinScaP) at the hemiplegic (IwS)/ dominant (controls) side of every participant. IwS were assessed in their respective rehabilitation centers and controls were tested in our research center. The entire assessment lasted 20 minutes.

Fifteen IwS were measured twice (same day) to assess test-retest reliability of the ClinScaP. The time between both measurement sessions varied between 4 and 7 hours, depending on the person's availability. Every anatomical landmark was palpated and/or marked again during the second measurement session.

The ClinScaP consists of five tests, with several subtests, and was always in the order described below (see Fig. 1. Further details can be found in Table 1).

Test 1: Observation of tilting and winging

While seated upright in a chair with low back support, the presence (score 1) or absence (score 0) of scapular tilting and winging was scored. This scoring was done by observing the participant's scapular position on the thorax during rest (both arms alongside the body, thumbs pointing forward) and during active unloaded forward flexion. Participants were instructed to move bilaterally at a rate of 3 seconds up toward their maximal forward flexion, and 3 seconds down toward the rest position. Observation was done from a dorsal and lateral position. Presence of tilting or winging indicated a prominence of the inferior tip of the scapula dorsally or of the medial scapular border, respectively (Kibler, Sciascia, & Wilkes, 2012; Struyf et al., 2009). Palpation was used to verify anatomical landmarks. A total score was calculated for observation at rest and during movement. Score '0' indicated no presence of tilting or winging, score '1' the presence of tilting or winging and score '2' the presence of both tilting and winging.

Test 2: Shoulder girdle position

Three different measures were used to evaluate shoulder girdle position, with specific palpation guidelines to ensure accurate palpation.

Acromial index (AI): This index was assessed with the participant lying supine, the arms relaxed alongside the body with the palm placed on the table. The participant was instructed to stay relaxed during the measurement. In this position, the acromial angle was palpated and the vertical distance between this angle and the table (cm) was measured with a sliding carpenter. This distance was divided by the

Table 1
Characteristics of the different tests of the ClinScaP

		Test characteristics				Psychometric properties		
		Active	Passive	Sit	Supine	Reliable[a]	IwS vs controls[b]	IwS with different levels of PAF[c]
Test 1: Observation of tilting and winging	At rest		X	X		X	X	X
	During movement	X		X		X	X	
Test 2: Shoulder girdle position	Pectoralis minor index		X	X				
	Scapular distance		X	X		X		
	Acromial index		X		X	X		
Test 3: Lateral rotation, inclinometry	Start (°)		X	X		X		
	At 45° FF (°)		X	X		X	X	X
	At 90° FF (°)		X	X		X	X	X
	At 135° FF (°)		X	X		X	X	X
Test 4: Maximal humeral elevation	X		X		X	X	X	
Test 5: Medial rotation test		X			X	X		

FF: forward flexion; [a]intra-observer reliability; [b]discriminative between IwS and controls; [c]discriminative between IwS with different levels of proximal arm function; PAF proximal arm function.

subject height (cm) and defined as the AI (no unit) (Nijs et al., 2005).

Pectoralis minor index (PMI): This index was assessed with the participant seated upright in a chair with low back support and the arms relaxed alongside the body. The resting length of the pectoralis minor muscle was assessed by measuring the length (measurement tape) between the inferior medial tip of the coracoids process and the caudal edge of rib four (at its sternal attachment). Both reference points were first palpated and marked using a pen. Participants were instructed to exhale during the palpation, marking and measurement itself. The PMI (no unit) was defined as the pectoralis minor resting length (cm) divided by the subject height (cm) (Borstad & Ludewig, 2005; Struyf, Meeus, et al., 2014).

Scapular distance test (SDT): This test assesses the position of the scapula on the trunk in an upright-seated position with low back support with the arms relaxed alongside the body. The SDT (no unit) was calculated by dividing the distance between the acromial angle and the spinous process of T3 (cm) by the distance between the acromial angle and the scapular trigonum (cm). Anatomical landmarks were first palpated and marked using a pen, and distances were subsequently measured with flexible measurement tape (DiVeta et al., 1990).

Test 3: Scapular lateral rotation

Scapular lateral rotation was assessed with an inclinometer (Plurimeter-V gravity inclinometer, Dr Rippstein, Switserland), while participants were seated upright with low back support. The inclinometer was held manually on the scapular spine by the skilled physiotherapist, while an assisting physiotherapist passively elevated the participant's arm in the sagittal plane (forward flexion) with the elbow extended and the thumb pointing upward. The amount of lateral rotation (degrees) was read from the inclinometer at rest (arm alongside the body), and at 45°, 90° and 135° of passive forward flexion (determined by goniometry) (Watson et al., 2005).

Test 4: Maximal active humeral elevation

While seated upright with low back support, the maximal range of active humerothoracic elevation in the sagittal plane (forward flexion) was read from a goniometer (degrees). Participants were instructed to extend the elbow and to keep the thumb pointing upward during movement.

Test 5: Medial rotation test

This test assessed scapular dynamic control while participants laid supine with the upper arm passively supported by a wedge in 90° of humerothoracic scapular plane elevation (30° anterior to the frontal plane), and the elbow flexed. While actively performing a movement towards glenohumeral internal rotation, i.e. moving the forearm towards the table, the participant was instructed to keep the scapula still. Meanwhile, the assessor palpated the anterior humeral head and the coracoid process and judged the amount of anterior humeral translation and scapular movement. Aberrant dynamic control indicated excessive anterior humeral translation (more than 4 mm, judged by palpation) or scapular movement (more than 6 mm, judged by palpation in the direction of anterior tilt, downward rotation or scapular elevation) before 60° of internal glenohumeral rotation. A total score of '0' indicated correct humeral translation and scapular movement; a score of '1' aberrant humeral translation or aberrant scapular movement; and a score of '2' aberrant humeral translation and aberrant scapular movement. Every participant received some practice trials before the formal test was executed (Lluch et al., 2014; Morrissey et al., 2008).

2.3. Statistical analysis

Descriptive statistics were used to document general characteristics for each group. A one-way ANOVA and *post-hoc* Tukey test were used to assess differences in age and time since stroke between the low, moderate and high PAF groups and the IwS included in the reliability assessment, and to assess differences in age between the low, moderate and high PAF groups and controls.

Bland-Altman plots were constructed for the measures of shoulder girdle position (AI, PMI, SDT – test 2), inclinometry (test 3) and maximal humeral elevation (test 4), to display the data graphically and to examine the distribution around the zero line. A 95% confidence interval was calculated (mean difference ± 1.96* $SD_{\text{mean difference}}$) to identify systematic variance (i.e. zero line not included in the 95% CI) or outliers. To assess heteroscedasticity, correlations between the mean of the two test sessions and the difference between the two test sessions were calculated.

Test-retest reliability of the measures of shoulder girdle position (AI, PMI, SDT – test 2), inclinometry (test 3) and maximal humeral elevation (test 4) was assessed with the intraclass correlation coefficient ($ICC_{2,1}$), with 95% confidence interval (CI). Standard error of measurement (SEM) based on the square root of the mean square error term from the two-way ANOVA (Weir, 2005), and minimal detectable change (MDC, defined as SEM * 1.96 * $\sqrt{2}$) were also reported (Wagner, Rhodes, & Patten, 2008). ICCs > 0.80 were considered very high, 0.60–0.79 moderately high, 0.40–0.59 moderate and < 0.40 low (Katz, Larson, Phillips, Fossel, & Liang, 1992). Agreement of scoring between sessions for the observation of tilting and winging (test 1) and for the medial rotation test (test 5) was calculated by weighted Kappa (K). $K < 0$ reflected 'poor', 0 to 0.20 'slight', 0.21 to 0.4 'fair', 0.41 to.60 'moderate', 0.61 to 0.8 'substantial', and above 0.81 'almost perfect' agreement (Landis & Koch, 1977).

An ICC or K value above 0.70 on a test was considered to indicate sufficient reliability or agreement for that specific test to be used in future clinical research.

Normal distribution of the data (test 2, 3, and 4) was verified with the Kolmogorov–Smirnov test. Group differences between controls and IwS were assessed using *t*-tests (test 2, 3, and 4) and Mann-Whitney tests (test 1 and 5) for independent samples. Subsequently, group differences between the low, moderate and high PAF group were assessed using a one-way ANOVA and *post-hoc* Tukey tests (test 2, 3, and 4), or a Kruskal-Wallis analysis and *post-hoc* Mann-Whitney tests (test 1 and 5). The level of significance was set at α-level 0.05 for the main effects, with *post-hoc* Bonferoni correction α-level of 0.0167. All statistics were done using SPSS version 22.

3. Results

3.1. Participants

Fifty-seven IwS (38 male, age 62 ± 14 years) were categorized into the low PAF group ($N = 17$, age 64 ± 10; time since stroke 31 ± 27 weeks; 6 right hemiplegia; 13/4 cortical/subcortical lesion; FM elbow-shoulder score 9 ± 4), the moderate PAF group ($N = 19$, age 66 ± 17; time since stroke 25 ± 16 weeks; 8 right hemiplegia; 13/6 cortical/subcortical lesion; FM elbow-shoulder score 23 ± 2), and the high PAF group ($N = 21$, age 58 ± 12; time since stroke 22 ± 38 weeks; 10 right hemiplegia; 19/2 cortical/subcortical lesion; FM elbow-shoulder score 32 ± 3). Additionally, 15 healthy controls were measured (8 male, age 52 ± 13 years).

Fifteen IwS were measured twice in the context of test-retest reliability analysis (4 low, 6 moderate and 5 high PAF; age 69 ± 9 years; time since stroke 18 ± 7 weeks; 6 right hemiplegia; 12/3 cortical/subcortical lesion; FM elbow-shoulder score 22 ± 7).

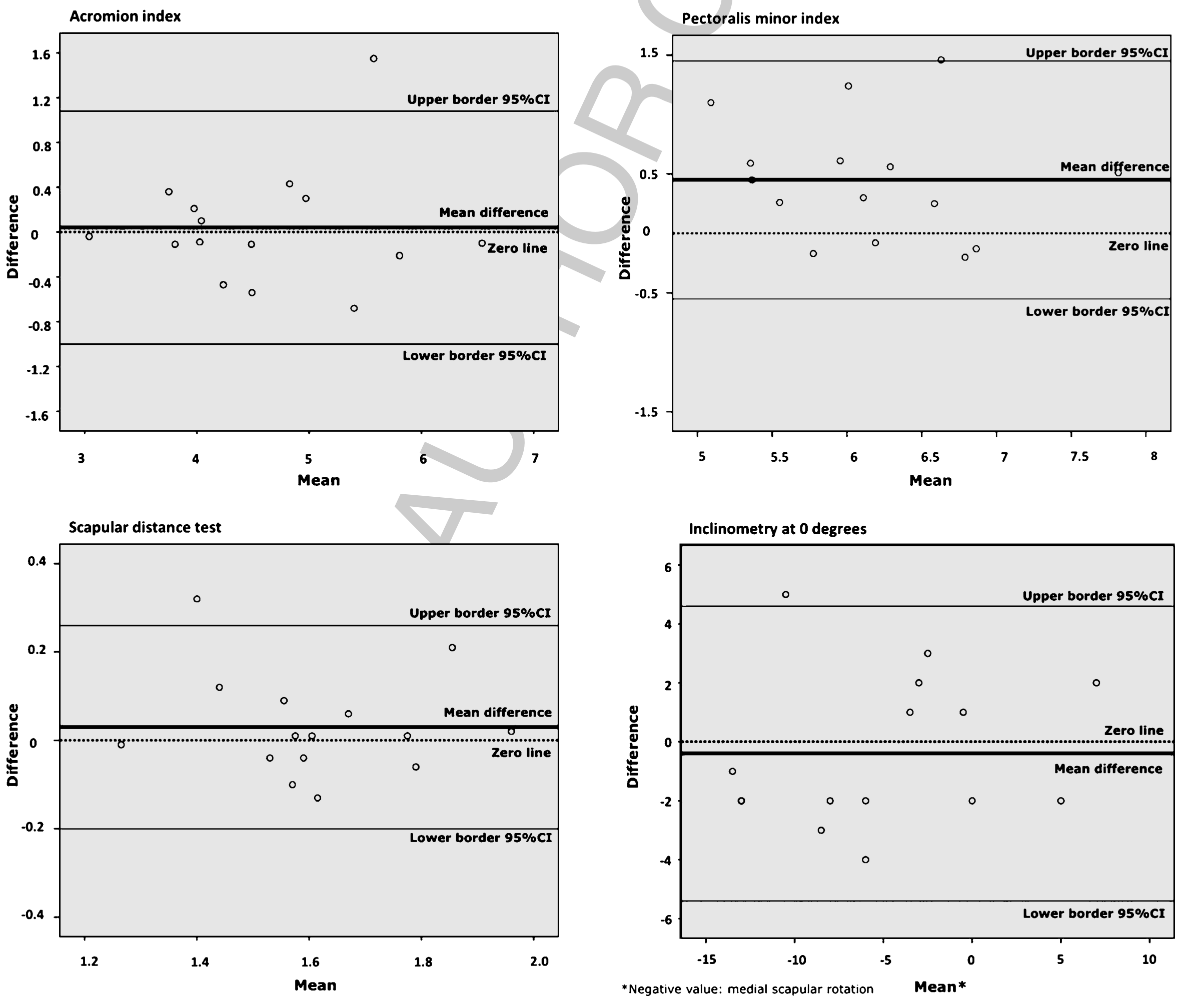
No significant differences were found between the low, moderate and high PAF group and the reliability group for age or time since stroke.

3.2. Reliability

There were no missing values for the reliability analysis, except for inclinometry at 135° for two IwS with low PAF. Reliability analyses for this measure is thus based on 13 IwS in total.

Bland-Altman plots are presented in Fig. 2 and show an equal distribution of data around the zero line for all test, except inclinometry at 45° and the PMI, there is no systematic variance (zero always included in the 95% CI). For inclinometry at 45° and the PMI, data points were more often distributed under or above the zero line, respectively. Inspection of inclinometry at 45° indicated a trend toward heteroscedasticity. However, no significant correlations were found between the mean of both test sessions and the difference between both for any of the tests, indicating uniform variability across the mean outcome (no data-heteroscedasticity). Based on the 95% CI, one outlier was identified for every test. Reliability analyses are presented for the entire sample ($n = 15$) as well as for the sample with the outlier excluded ($n = 14$).

For the entire sample, ICCs were very high for test 2, 3 and 4 of the ClinScaP (>0.81), except the PMI (0.66). For the sample without outlier, all ICCs were very high (>0.85). Almost perfect agreement was found for observation of winging and tilting during movement (0.89); and substantial agreement for



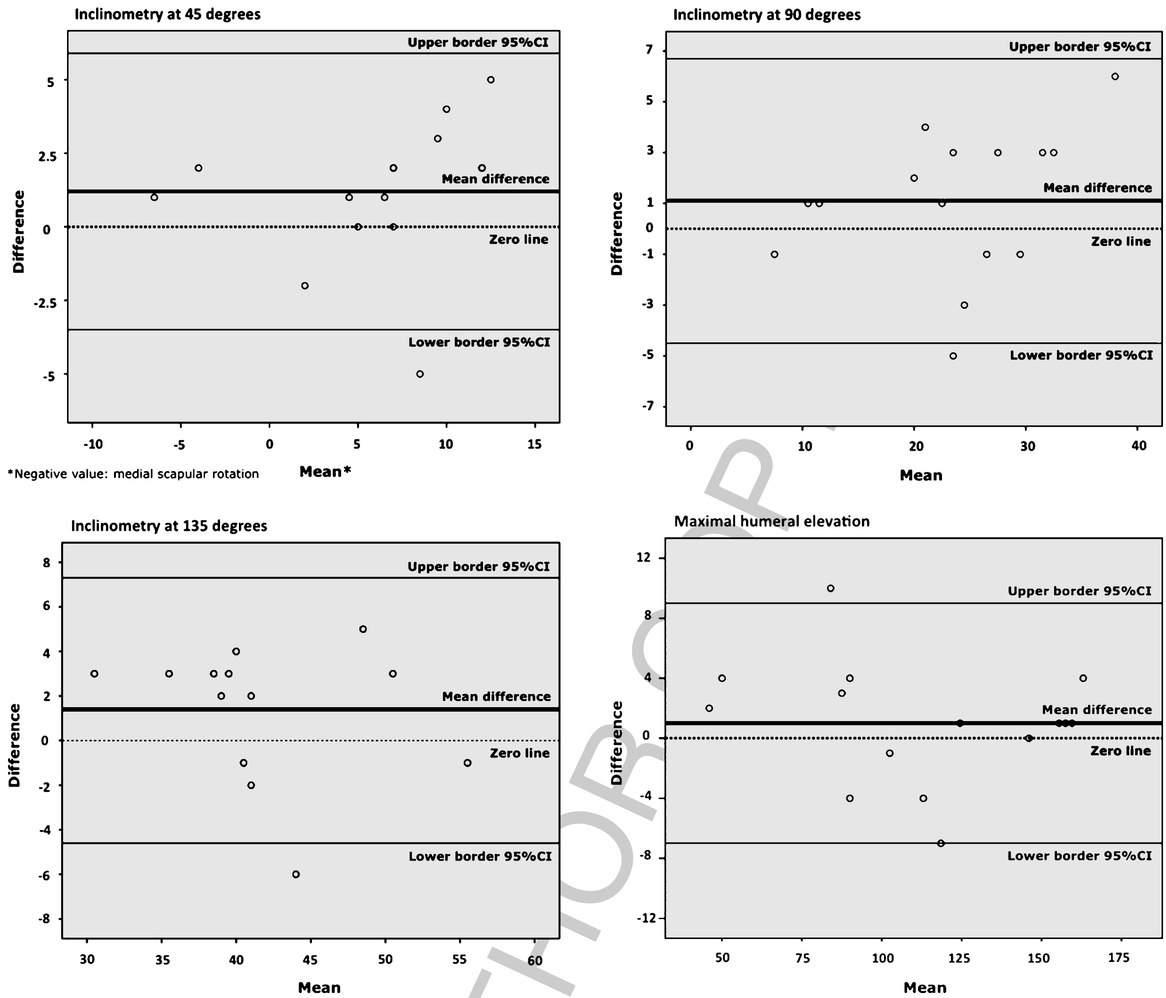


Fig. 2. Bland-Altman plots: difference between two measurement sessions versus the mean of both.

observation at rest (0.77) and for the medial rotation test (0.73). All ICCs and K-values, together with SEM and MDC values are presented in Table 2. Based on the data from the entire sample, the PMI was not considered reliable enough using the cut-off score of 0.70.

3.3. *Assessment of group differences*

Average values are presented for controls and every subgroup of IwS in Table 3.

Despite the requirement of a minimal range of 45° of active humeral elevation, the presence of tilting and winging during movement could not be scored in six participants with low PAF due to insufficient active arm elevation. Measuring lateral rotation by inclinometry at 135° of passive forward flexion was possible in only two participants with low PAF. As such, in part 1 of this section (*Differences between IwS and controls*), only 51/57 IwS were included for the analysis of group differences for observation during movement, and only 42/57 for the analysis of group differences in inclinometry at 135°. In part 2 of this section (*Differences between IwS with different levels of PAF*), only 11/17 participants of the low PAF group were included in the analysis of group differences for observation during movement. Lateral rotation by inclinometry at 135° of passive forward flexion was only compared between the moderate and high PAF group.

3.3.1. *Differences between IwS and controls*

Presence of tilting and winging at rest ($p = 0.012$) and during movement ($p = 0.007$) was more often seen in IwS than in healthy controls. Controls also had significantly less lateral rotation at 45° ($p = 0.004$),

Table 2
Reliability of the ClinScaP

		Complete sample ($n = 15$)				Outlier excluded ($n = 14$)					
		ICC	(95% CI)	SEM	MDC	ICC	(95% CI)	SEM	MDC	K	(95% CI)
Test 1: Observation	At rest									0.77	(0.54–1.00)
	During movement									0.89	(0.79–1.00)
Test 2: Shoulder girdle position	Pectoralis minor index	0.66	(0.09-0.89)	0.39	1.08	0.85	(0.32-0.96)	0.31	0.87		
	Scapular distance test	0.81	(0.53-0.93)	0.05	0.15	0.94	(0.81-0.98)	0.05	0.13		
	Acromial index	0.86	(0.62-0.95)	0.42	1.18	0.97	(0.90-0.99)	0.24	0.67		
Test 3: Lateral rotation (inclinometry)	Start (°)	0.94	(0.83-0.98)	1.59	4.40	0.97	(0.91-0.99)	1.25	3.46		
	At 45° humeral FF (°)	0.88	(0.65-0.96)	1.58	4.38	0.96	(0.68-0.99)	1.07	2.96		
	At 90° humeral FF (°)	0.95	(0.85-0.98)	1.47	4.07	0.98	(0.90-0.99)	1.67	4.62		
	At 135° humeral FF (°)	0.83	(0.48-0.96)	3.27	9.05	0.96	(0.67-0.99)	1.72	4.77		
Test 4: Max humeral elevation		0.99	(0.99-1.00)	2.44	6.76	0.99	(0.99-0.99)	1.76	4.89		
Test 5: Medial rotation test										0.73	(0.44–1.00)

Max: Maximal; FF: Forward flexion; ICC: Intraclass correlation coefficient; CI: Confidence interval; SEM: Standard error of the measurement; MDC: Minimal detectable change; K: Weighted kappa.

90° ($p = 0.001$) and 135° of forward flexion ($p = 0.01$), and more active humeral elevation ($p = 0.000$) compared to IwS. No differences were found for shoulder girdle position or medial rotation.

3.3.2. *Differences between IwS with different levels of PAF*

Significant differences between groups were found for presence of tilting and winging at rest ($p = 0.012$), but not during movement ($p = 0.055$). *Post-hoc* tests indicated that tilting and winging at rest occurred significantly more often in participants with moderate compared to high PAF ($p = 0.010$).

Significant group differences were also found for inclinometry at 45° and 90° of passive forward flexion ($p = 0.004$ and $p = 0.001$, respectively). *Post-hoc* analysis showed that IwS with high PAF had significantly less scapular lateral rotation at 45°, compared to the moderate PAF group ($p = 0.008$) and at 90° compared to the low and moderate PAF group ($p = 0.003$ and $p = 0.006$, respectively). At 135° of passive forward flexion, the high PAF group showed significantly less scapular lateral rotation compared to the moderate PAF group ($p = 0.002$).

The amount of active humeral elevation differed significantly between groups ($p < .001$), whereby IwS with moderate and high PAF had significantly more active humeral elevation than those in the low PAF group ($p < .0001$ and $p < .0001$); and IwS with high PAF had significantly more active elevation range than those with moderate PAF ($p < .0001$). We found no differences for shoulder girdle position or medial rotation.

An overview of results for the different tests of ClinScaP can be found in Table 1.

4. Discussion

A prerequisite for the application of a clinical measure is its potential to differentiate between a pathological or non-pathological situation or between various degrees of dysfunction. Moreover, before any assessment is of value in a clinical decision-making process or to evaluate treatment efficacy, its reliability needs to be confirmed. In this study, we proposed a specific measurement protocol for scapulohumeral control (ClinScaP) for IwS, which is easily available and directly applicable in rehabilitation centers or in private practices and assessed test-retest reliability. We furthermore determined the protocol's ability to differentiate between controls and IwS in general,

Table 3
Descriptive statistics for the Fugl-Meyer and the different tests of the ClinScaP in IwS with different levels of proximal arm function

		Low prox arm function		Moderate prox arm function		High prox arm function		Controls	
		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Fugl-Meyer	Proximal[a]	9.3	(4.1)	23.8	(1.6)	31.8	(3.2)		
	Upper limb[b]	26.8	(9.9)	49.2	(5.5)	57.4	(4.1)		
Test 2: Shoulder girdle position	Pectoralis minor index	5.9	(1.0)	6.0	(0.7)	5.7	(1.0)	5.5	(0.5)
	Scapular distance	1.6	(0.1)	1.6	(0.4)	1.6	(0.2)	1.5	(0.1)
	Acromial index	4.6	(1.0)	4.0	(0.5)	4.5	(0.9)	4.4	(0.7)
Test 3: Lateral rotation, inclinometry	Start (°)	1.9[c]	(9.1)	2.5[c]	(6.0)	4.0[c]	(5.2)	2.3[c]	(4.6)
	At 45° of FF (°)	7.9	(6.1)	8.2[d]	(5.1)	2.7	(4.9)	2.4[e]	(3.5)
	At 90° of FF (°)	26.5[d]	(7.6)	25.5[d]	(6.1)	18.3	(6.9)	12.6[e]	(8.9)
	At 135° of FF (°)			48.1[d]	(7.9)	38.2	(5.8)	36.7[e]	(5.6)
Test 4: Maximal humeral elevation		61.8[d,f]	(21.3)	118.8[d]	(23.2)	152.5	(13.3)	164.1[e]	(9.6)

		Low prox arm function			Moderate prox arm function			High prox arm function			Controls		
	Score (%)	0	1	2	0	1	2	0	1	2	0	1	2
Test 1: Observation	at rest	29.4	23.5	47.1	26.3	15.8[d]	57.9	61.9	23.8	14.3	66.6[e]	33.3	0
	during movement	54.5	0	55.5	21.1	21.1	57.8	42.9	33.3	23.8	80.0[e]	13.3	6.7
Test 5: Medial rotation test		29.4	11.8	58.8	31.6	21	47.4	52.4	23.8	23.8	73.3	0	26.7

FF: Forward flexion; prox: Proximal; [a]:Shoulder and elbow parts of the Fugl-Meyer upper limb motor scale; [b]:Fugl-Meyer upper limb motor scale; [c]:Medial rotation; [d]:Significantly different from high proximal arm function group; [e]:Significantly different from total group of patients with stroke; [f]:Significantly different from moderate proximal arm function group.

and between IwS with different levels of PAF. In this way, it enables therapists to clinically identify scapular characteristics or dysfunctions, which could be related to various levels of PAF. The included tests in the ClinScaP were chosen based on their acceptable psychometric properties in musculoskeletal rehabilitation and on our assumption that these tests were related to a specific scapular rotation (DiVeta et al., 1990; Gibson, Goebel, Jordan, Kegerreis, & Worrell, 1995; Lluch et al., 2014; Nijs et al., 2005; Struyf, Meeus, et al., 2014; Struyf et al., 2009; Watson et al., 2005). We furthermore opted to add static as well as dynamic tests, deemed feasible for IwS, even with a low PAF. Lateral rotation was therefore assessed during passive forward flexion. Additionally, this allowed maximal standardization of the test, i.e. joint angles were obtained at exactly 45°, 90° and 135° of humerothoracic forward flexion. Observation at rest, and the different tests for shoulder girdle position (PMI, AI, SDT) were chosen as passive measurements of scapular positional alterations, linked with e.g. inflexibilities or shortening of soft tissue structures around the shoulder joint, contributing to shoulder disorders (e.g. pectoralis minor) (Borstad & Ludewig, 2005). However, dynamic measures are considered more functional than static measures, and thus observation of tilting and winging during movement was also included in the protocol. This test is assumed to provide information on e.g. delayed lower trapezius activation or decreased serratus anterior activity. Lastly, the medial rotation test and maximal active humeral elevation were added to dynamically assess scapular and scapulohumeral control, respectively.

Current study results could not confirm an acceptable reliability for the PMI in IwS with different levels of PAF. Measurement inaccuracies due to the difficult palpation areas and the dependence of the participant's respiration for the assessment of pectoralis minor length, could explain the lower reliability for the PMI.

The clinical value of the ClinScaP also relies on its ability to differentiate between IwS and controls, or between IwS with different levels of PAF. Results suggested that both passive, i.e. lateral rotation by inclinometry and observation at rest, as active measures, i.e. observation during movement and maximal active humeral elevation, are relevant measures for therapists to use in clinical practice in IwS. Humeral motion can create early scapular motion by placing tension on a shortened glenohumeral capsule or stiff posterior-inferior glenohumeral muscles (Borich et al., 2006; Kibler et al., 2012; Laudner, Moline, & Meister, 2010). Hence, the increase in scapular lateral rotation and presence of anterior tilting and winging seen in IwS with moderate PAF compared to high PAF can be caused by restrictions in posterior glenohumeral structures. The reported significant differences in lateral rotation are moreover larger than the magnitude of the minimal detectable change, and can thus be interpreted as real differences. Together, results suggest that the inclusion of glenohumeral capsular or muscular stretching techniques in the rehabilitation of IwS with a moderate PAF might be beneficial to improve scapulohumeral control and hence arm function.

The PMI was considered less reliable in this study and could, together with the AI, SDT and medial rotation test, not differentiate between groups. The lack of differentiation of the shoulder girdle position tests (PMI, AI, SDT) might be due to the fact that these were measured with the participant's arm alongside of the body instead of an arm elevated position. Although not significantly different between IwS and controls, results for the medial rotation test, executed in an elevated arm position, did show a trend (p.056) toward reduced scapular control in IwS. The aforementioned tests are thus considered less relevant in clinical practice to differentiate between IwS and controls or between IwS with different levels of PAF. However, this selection of tests should only be applied to IwS similar to our included study sample, i.e. IwS without shoulder pain.

4.1. Limitations

In the current study, we did not account for the side and type of stroke or the amount of brain damage. Furthermore, participants were grouped based on the shoulder and elbow motor items of the Fugl-Meyer upper limb motor scale. As such, other upper limb impairments such as spasticity or sensory deficits were not taken into account.

4.2. Future perspectives

A first step would be to assess the feasibility and reliability of the entire ClinScaP in IwS with shoulder pain. This will allow gaining a deeper understanding of the development of shoulder pain in IwS. This is especially of interest since the alterations found in IwS with moderate compared to high PAF, i.e. more often presence of tilting and winging at rest and increased lateral rotation, are known to be related to shoulder symptoms and pathology (Borstad & Ludewig, 2002; Niessen et al., 2008). Future studies should also assess the relation between objective scapular measures based on kinematic movement analysis and the different ClinScaP tests.

Finally, inter-observer reliability of the ClinScaP remains to be confirmed in IwS.

In conclusion, observation of tilting and winging, inclinometry and maximal humeral elevation showed good reliability results, and these tests revealed distinct alterations in scapular characteristic in IwS. From a clinical perspective, the availability of the assessment of static scapular position (observation at rest, inclinometry during passive arm forward flexion) and dynamic movement control (observation during movement, maximal active humeral elevation), facilitates the understanding of the relation between scapulohumeral control and arm function in IwS. The knowledge gained from these tests will thus contribute to the further delineation of a treatment plan to target specific scapulohumeral dysfunctions, i.e decreasing scapular lateral rotation, optimizing scapular position on the thorax and enhancing scapular motor control, and eventually improve arm function.

Conflict of interest

None to declare.

References

Borich, M. R., Bright, J. M., Lorello, D. J., Cieminski, C. J., Buisman, T., & Ludewig, P. M. (2006). Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther*, *36*(12), 926-934. doi:10.2519/jospt.2006.2241

Borstad, J. D., & Ludewig, P. M. (2002). Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. *Clin Biomech (Bristol, Avon)*, *17*(9-10), 650-659.

Borstad, J. D., & Ludewig, P. M. (2005). The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. *J Orthop Sports Phys Ther*, *35*(4), 227-238. doi:10.2519/jospt.2005.35.4.227

De Baets, L., Jaspers, E., Janssens, L., & Van Deun, S. (2014). Characteristics of neuromuscular control of the scapula after stroke: A first exploration. *Front Hum Neurosci*, *8*, 933. doi:10.3389/fnhum.2014.00933

DiVeta, J., Walker, M. L., & Skibinski, B. (1990). Relationship between performance of selected scapular muscles and scapular abduction in standing subjects. *Phys Ther*, *70*(8), 470-476; discussion 476-479.

Frontera, W. R., Grimby, L., & Larsson, L. (1997). Firing rate of the lower motoneuron and contractile properties of its muscle fibers after upper motoneuron lesion in man. *Muscle Nerve*, *20*(8), 938-947.

Gibson, M. H., Goebel, G. V., Jordan, T. M., Kegerreis, S., & Worrell, T. W. (1995). A reliability study of measurement techniques to determine static scapular position. *J Orthop Sports Phys Ther*, *21*(2), 100-106. doi:10.2519/jospt.1995.21.2.100

Grimby, L., Hannerz, J., & Ranlund, T. (1974). Disturbances in the voluntary recruitment order of anterior tibial motor units in spastic paraparesis upon fatigue. *J Neurol Neurosurg Psychiatry*, *37*(1), 40-46.

Katz, J. N., Larson, M. G., Phillips, C. B., Fossel, A. H., & Liang, M. H. (1992). Comparative measurement sensitivity of short and longer health status instruments. *Med Care*, *30*(10), 917-925.

Kibler, W. B., & Sciascia, A. (2010). Current concepts: Scapular dyskinesis. *Br J Sports Med*, *44*(5), 300-305. doi:10.1136/bjsm.2009.058834

Kibler, W. B., Sciascia, A., & Wilkes, T. (2012). Scapular dyskinesis and its relation to shoulder injury. *J Am Acad Orthop Surg*, *20*(6), 364-372. doi:10.5435/jaaos-20-06-364

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159-174.

Laudner, K. G., Moline, M. T., & Meister, K. (2010). The relationship between forward scapular posture and posterior shoulder tightness among baseball players. *Am J Sports Med*, *38*(10), 2106-2112. doi:10.1177/0363546510370291

Lluch, E., Benitez, J., Duenas, L., Casana, J., Alakhdar, Y., Nijs, J., & Struyf, F. (2014). The shoulder medial rotation test: An intertester and intratester reliability study in overhead athletes with chronic shoulder pain. *J Manipulative Physiol Ther*, *37*(3), 198-205. doi:10.1016/j.jmpt.2013.12.012

Lum, P. S., Burgar, C. G., & Shor, P. C. (2003). Evidence for strength imbalances as a significant contributor to abnormal synergies in hemiparetic subjects. *Muscle Nerve*, *27*(2), 211-221. doi:10.1002/mus.10305

McComas, A. J., Sica, R. E., Upton, A. R., & Aguilera, N. (1973). Functional changes in motoneurones of hemiparetic patients. *J Neurol Neurosurg Psychiatry*, *36*(2), 183-193.

Morrissey, D., Morrissey, M. C., Driver, W., King, J. B., & Woledge, R. C. (2008). Manual landmark identification and tracking during the medial rotation test of the shoulder: An accuracy study using three-dimensional ultrasound and motion analysis measures. *Man Ther*, *13*(6), 529-535. doi:10.1016/j.math.2007.07.009

Neer, C. S. 2nd, & Foster, C. R. (1980). Inferior capsular shift for involuntary inferior and multidirectional instability of the shoulder. A preliminary report. *J Bone Joint Surg Am*, *62*(6), 897-908.

Niessen, M., Janssen, T., Meskers, C., Koppe, P., Konijnenbelt, M., & Veeger, D. (2008). Kinematics of the contralateral and ipsilateral shoulder: A possible relationship with post-stroke shoulder pain. *J Rehabil Med*, *40*(6), 482-486. doi:10.2340/16501977-0201

Nijs, J., Roussel, N., Vermeulen, K., & Souvereyns, G. (2005). Scapular positioning in patients with shoulder pain: A study examining the reliability and clinical importance of 3 clinical tests. *Arch Phys Med Rehabil*, *86*(7), 1349-1355.

Platz, T., Pinkowski, C., van Wijck, F., Kim, I. H., di Bella, P., & Johnson, G. (2005). Reliability and validity of arm function assessment with standardized guidelines for the Fugl-Meyer Test, Action Research Arm Test and Box and Block Test: A multicentre study. *Clin Rehabil*, *19*(4), 404-411.

Rundquist, P. J., Dumit, M., Hartley, J., Schultz, K., & Finley, M. A. (2012). Three-dimensional shoulder complex kinematics in individuals with upper extremity impairment from chronic stroke. *Disabil Rehabil*, *34*(5), 402-407.

Struyf, F., Meeus, M., Fransen, E., Roussel, N., Jansen, N., Truijen, S., & Nijs, J. (2014). Interrater and intrarater reliability of the pectoralis minor muscle length measurement in subjects with and without shoulder impingement symptoms. *Man Ther*, *19*(4), 294-298. doi:10.1016/j.math.2014.04.005

Struyf, F., Nijs, J., De Coninck, K., Giunta, M., Mottram, S., & Meeusen, R. (2009). Clinical assessment of scapular positioning in musicians: An intertester reliability study. *J Athl Train*, *44*(5), 519-526. doi:10.4085/1062-6050-44.5.519

Struyf, F., Nijs, J., Horsten, S., Mottram, S., Truijen, S., & Meeusen, R. (2011). Scapular positioning and motor control in children and adults: A laboratory study using clinical measures. *Man Ther*, *16*(2), 155-160. doi:10.1016/j.math.2010.09.002

Struyf, F., Nijs, J., Mollekens, S., Jeurissen, I., Truijen, S., Mottram, S., & Meeusen, R. (2013). Scapular-focused treatment in patients with shoulder impingement syndrome: A randomized clinical trial. *Clin Rheumatol*, *32*(1), 73-85. doi:10.1007/s10067-012-2093-2

Struyf, F., Nijs, J., Mottram, S., Roussel, N. A., Cools, A. M., & Meeusen, R. (2014). Clinical assessment of the scapula: A review of the literature. *Br J Sports Med*, *48*(11), 883-890. doi:10.1136/bjsports-2012-091059

Wagner, J. M., Rhodes, J. A., & Patten, C. (2008). Reproducibility and minimal detectable change of three-dimensional kinematic analysis of reaching tasks in people with hemiparesis after stroke. *Phys Ther*, *88*(5), 652-663. doi:10.2522/ptj.20070255

Watson, L., Balster, S. M., Finch, C., & Dalziel, R. (2005). Measurement of scapula upward rotation: A reliable clinical procedure. *Br J Sports Med*, *39*(9), 599-603. doi:10.1136/bjsm.2004.013243

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res*, *19*(1), 231-240. doi:10.1519/15184.1