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STOP USING THE ASHWORTH SCALE FOR THE ASSESSMENT OF SPASTICITY

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ABSTRACT

Aim. Many studies have been performed upon the methodological qualities of the (modified) Ashworth Scale, but overall these studies seem insufficiently conclusive. Aim of this study is to investigate the construct validity and inter-rater reliability of the Ashworth Scale (AS) for the assessment of spasticity in upper and lower extremities.

Method. A cross-sectional study on spasticity in the elbow flexors (part 1) and knee extensors (part 2) was carried out. In both parts AS was assessed, while muscle activity and resistance was recorded simultaneously, in patients with upper motor neuron syndrome. Each patient was measured by three raters.

Results. Thirty patients participated, nineteen in each part of the study. For elbow flexor muscles, AS was not significantly associated with electromyographic parameters, except for rater 2 ($\rho = 0.66$, $p < 0.01$). A moderate significant association was found with resistance ($0.54 \leq \rho \leq 0.61$, $p < 0.05$). For knee extensors, AS scores were moderately associated with muscle activity ($0.56 \leq \rho \leq 0.66$, $p < 0.05$) and also with resistance ($0.55 \leq \rho \leq 0.87$, $p < 0.05$). Intraclass correlation coefficient for absolute agreement was 0.58 for elbow flexors and 0.63 for knee extensors. In linear mixed model analysis the factor Rater appeared to be highly associated with AS.

Conclusion. Validity and reliability of the Ashworth Scale is insufficient to be used as a measure for spasticity.

INTRODUCTION

Spasticity is a common phenomenon in patients with upper motor neuron syndrome and is characterized by involuntary muscle activity [1]. Traditionally, spasticity is defined as a motor disorder characterized by a velocity dependent increase in tonic stretch reflexes resulting from hyperexcitability of the stretch reflex [2] and is particularly present in the anti-gravity muscles, like the knee extensors and the elbow flexors [3].

In clinical practice as well as in scientific research either the Ashworth Scale (AS) [4] or its modified version (MAS) [5] is the most commonly used method for the measurement of spasticity.[6, 7] In many neurology books this scale is still referred to as being the principal method for assessing spasticity (e.g. [8]). However, its methodological limitations are now increasingly being acknowledged.[6, 7, 9, 10] While performing the test the joint under investigation is passively rotated and the examiner rates the perceived resistance during the movement. This resistance is scored on an ordinal scale from 0 to 4. To be a measure for spasticity, the (M)AS can only be valid when the increase in resistance to passive movement is exclusively associated with an increase in neural, stretch reflex activity.[11, 12, 13] However, this is probably not the case as the resistance to passive movement is a sum total of reflex muscle activity and non-neural mechanical characteristics. It is influenced by changes in visco-elastic properties of joint structures and soft tissues after an upper motor neuron lesion.[13, 14] In addition, changes in mechanical muscle-fibre properties might contribute to spastic muscle tone.[3] Biomechanical changes are hard to differentiate from reflexive muscle activity without the use of highly sophisticated

instruments, although in clinical practice nerve blocks with local anaesthetics can be of assistance.[15]

Two comprehensive reviews have been published that address the validity of the (M)AS.[6, 7] Both reviews found that associations of (M)AS with electromyographic parameters were moderate, and the association with objective measures of resistance was generally stronger.

Besides concerns with regard to validity, the reliability of the AS is questioned as well. Platz et al. concluded that the intra- and inter-rater reliability of the (M)AS appeared to vary highly between studies.[7] Generally somewhat higher levels of reliability were found in the upper extremity compared to the lower extremity,[7, 16, 17] which could be due to the larger mass of the legs. Another factor that might affect reliability is lack of standardization of the (M)AS.[6, 18, 19] Possibly, factors like the velocity and range of motion may affect the perceived resistance, but these have never been quantified for this scale so far.

In summary, several studies about the methodological qualities of the (M)AS have been performed, investigating either the validity or the reliability of the scale. Overall, these studies are not conclusive and that has led to the continued use of a measurement method with doubtful methodological qualities. Therefore, there is a need for a comprehensive study on the clinimetric properties of the AS, using a design that overcomes the major drawbacks of existing literature. The goal of present study was twofold: Firstly, to investigate the construct validity of the AS for the measurement of spasticity, and secondly, to assess the inter-rater reliability and identify potential sources of variability between raters. For these purposes, surface electromyography (sEMG) recording was performed during AS scoring by different trained raters, in both elbow flexor and knee extensor muscle groups. Additionally,

dynamometry recording was done simultaneously for objective assessment of resistance during passive movement.

METHODS

Study design and population

This cross-sectional study consisted of two parts: The first part focused on spasticity in elbow flexor muscles and the second part on spasticity in knee extensor muscles.

Patients with self-reported spasticity in the upper arm and/or upper leg following an upper motor neuron lesion were recruited from the in- and outpatient departments of a local Rehabilitation Centre. To take part in the study patients had to be able to understand simple commands. Presence of pain or severe contractures of the elbow or knee were exclusion criteria.

The study was approved by the local medical ethics committee. Patients signed informed consent before participation in the study.

Procedure

Each patient was measured by three raters. Patients were measured in random order, with 30-45 minutes of rest in between two ratings. The raters, three physicians and a physiotherapist involved in daily spasticity care and experienced with using the AS, were instructed in detail about the measurement protocol a few weeks prior to assessment during a group session. Before the actual measurement the full passive range of motion was assessed by the rater, starting from the position with maximum shortened muscles and rotating to the position of full muscle stretch at a low velocity. Subsequently, raters performed the movement twice at fast velocity throughout the entire range of motion. Raters noted the AS score on a form. In case of doubt, the lower score obtained was documented.

For measurement of the elbow flexors (part 1), patients were comfortable in supine position with the affected arm on a supporting scale, with the shoulder abducted to about 20° (picture 1). The rater rested one hand on the upper arm of the patient and the other on the palmar side of forearm just proximal to the wrist simultaneously holding the dynamometer. From the starting position of full elbow flexion the rater extended the elbow to maximum extension. For the measurement of the knee extensors (part 2) the patients were positioned lying on the non-tested side, with $\pm 45^\circ$ of hip flexion on the tested side (picture 2). The raters were instructed to hold the tested leg with one hand just above the knee and the other around the distal part of the lower leg holding the dynamometer that was fixed ventrally above the ankle. From the starting position of maximum knee extension the rater flexed the knee fully. The standardized positions were maintained without forceful stretching or discomfort for the patient. Patients were explicitly instructed to relax fully and not to react to stretches. Raters and patients were blinded for the sEMG and dynamometry output and other raters' scores.

[Insert pictures 1 and 2 about here]

Instrumentation

Surface EMG signals were obtained using bipolar, pre-gelled circular (diameter = 10 mm) electrodes (ARBO H93, solid gel), with an inter-electrode distance of 24 mm. A reference electrode was placed around the wrist.

Electrodes were placed on the elbow flexor muscles Biceps Brachii (BB) and Brachioradialis (BR), or on the knee extensor muscles Rectus Femoris (RF) and Vastus Lateralis (VL). Sensors on BB, RF and VL were placed according to the

electrode placement recommendations of the SENIAM-based protocol.[20] BR electrodes were placed at 1/4th of the line between the distal radius and the fossa cubit. A reference electrode was placed at the medial aspect of the contralateral wrist. For force measurements a handheld dynamometer (Biometrics M500) was used, which was positioned at the palmar aspect of the wrist or anterior aspect of the lower leg, such that the rater could easily hold it during AS scoring. In addition, the elbow or knee angle was registered using a mono-axial electronic goniometer, placed on the lateral side of the joint, to enable the characterization of the movement performed during measurement by determining start and end of the movement. All sensors were connected with the Mobi measurement device (Mobi, TMSi, The Netherlands), a blue tooth recording and processing system that allowed temporal synchronization of the sEMG signals with analogue data from the angle and force sensors. Sample frequency was 512 Hz and data were bandpass filtered at 15 - 256 Hz using 2nd order Butterworth filter.

Data analysis and outcome parameters

The AS was scored according to the original scale (score 0 – 4).[4]

Outcome parameters were selected in order to reflect (1) reflex muscle activity on stretch while rating the AS, using sEMG, and (2) the total resistance felt by the raters while rotating the limb, using a dynamometer.

From sEMG recordings, root mean square values (RMS; in μV) of each muscle during joint rotation were calculated, representing the average muscle activity during stretching of the muscle. Subsequently, the total amount of EMG activity was calculated by integrating the RMS during the whole joint rotation (area under the

curve, AUC_{muscle} ; in $\mu V \cdot \text{sec}$). The latter was considered to give better representation of the intensity of muscle activity during the whole rotation.

Similarly, the area under the force curve was calculated from the dynamometer data, representing the intensity of applied force or the resistance during joint rotation (Resistance; in $\text{Newton} \cdot \text{sec}$).

Goniometry recordings were used to determine the start and end points of the muscle stretching phase, from which movement characteristics during joint rotation, such as range of movement (ROM; in degrees), duration (Duration; in seconds) and mean angular velocity (Velocity; in deg/sec) were derived.

The parameters AS score and AUC_{muscle} were used as primary outcome measures.

Statistical analysis

Descriptive statistics were used for sociodemographic and outcome variables. Mean values of each instrumentally obtained parameter were computed out of the 2 performed elbow extension or knee flexion movements. In a few cases only one cycle was used for analysis, due to failure to perform one of the movements properly, indicated by the rater, or for technical reasons (e.g. recording problems).

Construct validity of AS for each rater separately was investigated, by calculating the association between AS and AUC_{muscle} , using Spearman's correlation coefficient.

Additionally, the correlation coefficient was calculated between AS, Resistance and Velocity.

Inter-rater reliability of the AS was evaluated first by calculating raw overall agreement between raters. Subsequently generalized kappa for three raters was calculated. In addition, the intraclass correlation coefficient (ICC) for absolute agreement was calculated.[21] A linear mixed model analysis was performed to get

insight in the weight of each independent variable (AUC_{muscle} , Resistance and covariate Velocity) in explaining the dependent variable AS. In order to explore the variability between raters, the factor Rater was added to the model as well. The ‘eyeball test’ was used to test the assumption of normally distributed residuals. The percentage of explained variance (1st level R^2) for the model was calculated according to the formula of Snijders and Bosker.[22]

For statistical analysis SPSS 11.5 was used. For calculation of the generalized kappa Excel software was used. Alpha was set at 0.05 for statistical significance.

RESULTS

Altogether thirty patients were included in this study, of which 19 patients participated in each part. The characteristics of both groups are summarized in table 1. In the first part of the study all 19 patients were measured by rater 1, 18 by rater 2 and 16 patients by rater 3. Dynamometry and sEMG data were partly missing in 3 patients. In part two all 19 patients were measured by raters 1, 3 and 4. Dynamometry and sEMG data were partly missing in one patient; dynamometry data were missing in another patient.

AS score '0' was rated in 22% of the measurements, '1' in 44%, '2' in 23%, '3' in 11% and '4' in 1% of the measurements, with comparable distributions in both parts of the study. During slow stretch no severe contractures were found.

Figure 1 shows an example of muscle activation patterns of knee extensors and resistance during AS scoring by rater 1. The medians and ranges of the movement characteristics during scoring for each rater are shown in table 2.

Table 1: Group characteristics

Characteristics	Part 1 (Elbow flexors) N=19	Part 2 (Knee extensors) N=19
Age, in yrs (mean \pm sd)	57 (\pm 13)	57 (\pm 16)
Male (n)	16	15
Diagnosis (n)		
Stroke	18	11
Cerebral palsy	1	2
Neuromuscular disease	0	4
Spinal cord injury	0	2

Table 2: Descriptive statistics (median, range) of the movement characteristics per rater

Elbow flexors (part 1)			
Parameter	Rater 1	Rater 2	Rater 3
ROM	97.3 (67.7 – 119.0)	104.0 (85.4 – 131.7)	90.9 (71.8 – 115.0)
Duration	0.97 (0.70 – 1.56)	1.54 (0.96 – 2.99)	1.37 (0.72 – 2.70)
Velocity	100.6 (57.9 – 156.0)	62.7 (33.2 – 126.7)	66.6 (34.0 – 123.3)
Knee extensors (part 2)			
Parameter	Rater 1	Rater 3	Rater 4
ROM	84.7 (51.6 – 99.8)	78.8 (47.7 – 97.2)	101.9 (68.7 – 119.3)
Duration	0.82 (0.46 – 2.08)	0.87 (0.49 – 2.47)	2.05 (0.57 – 4.02)
Velocity	112.9 (49.6 – 208.2)	91.7 (34.4 – 176.4)	50.9 (21.2 – 177.4)

Abbreviations: ROM, range of motion.

[Insert figure 1 about here]

Construct validity

Part 1 (Elbow flexor muscles)

The results for each rater are shown in table 3. For all raters AS was significantly moderately associated with Resistance. AS was not associated with sEMG parameters, except for rater 2, for whom a positive association was found with AUC_{BB} , but not with AUC_{BR} .

Table 3: Spearman correlation coefficients for the association between AS and muscle activity, resistance and angular velocity

Parameter	AS score elbow flexors (part 1)		
	Rater 1	Rater 2	Rater 3
AUC _{BB}	0.05	0.66**	0.07
AUC _{BR}	0.13	0.12	0.31
Resistance	0.55*	0.54*	0.61*
Velocity	-0.44	-0.73**	-0.65**
Parameter	AS score knee extensors (part 2)		
	Rater 1	Rater 3	Rater 4
AUC _{RF}	0.34	0.56*	0.54*
AUC _{VL}	0.57*	0.65**	0.66**
Resistance	0.67**	0.87**	0.55*
Velocity	-0.71**	-0.79**	-0.77**

* $p < 0.05$

** $p < 0.01$

Abbreviations: AS, Ashworth Scale; AUC, area under the curve; BB, Biceps Brachii; BR, Brachioradialis; RF, Rectus Femoris; VL, Vastus Lateralis.

Part 2 (Knee extensor muscles)

Table 3 shows the results of the knee extensor measurements. A consistent finding was the marked positive association between AS and Resistance across the three raters. In addition, all three raters showed a moderate positive correlation between AS and AUC_{VL}, rater 3 and 4 also between AS and AUC_{RF}.

Reliability

Part 1 (Elbow flexor muscles)

Overall agreement of AS scores between the raters 1 and 2 and between the raters 1 and 3 was 44%. Overall agreement between the raters 2 and 3 was 38%. The generalized kappa for the three raters ($n = 16$) was 0.20. The ICC for absolute agreement concerning the AS scores of the three raters was 0.58 (95% confidence interval 0.30 – 0.81).

Part 2 (Knee extensor muscles)

Overall agreement of AS scores between raters 1 and 3 was 32%. Between raters 1 and 4 it was 53% and between raters 3 and 4 it was 42%. The generalized kappa for the three raters ($n = 19$) showed very low agreement: $\kappa = 0.16$. ICC for absolute agreement was 0.63 (95% confidence interval 0.39 – 0.82).

The role of angular velocity in the variability between raters

Part 1 (Elbow flexor muscles)

Table 3 shows negative associations between AS and Velocity in raters 2 and 3 ($p < 0.01$). The association between Velocity, sEMG parameters and Resistance was explored further (table 4): In all raters, Velocity was highly negatively associated with Resistance. In rater 2, Velocity was also moderately negatively associated with AUC_{BB} ; in raters 2 and 3 with AUC_{BR} .

Table 4: Spearman correlation coefficients for the association between angular velocity, muscle activity and resistance per rater

Part 1			
Parameter	Rater 1	Rater 2	Rater 3
Velocity elbow extension			
AUC _{BB}	-0.18	-0.68**	-0.50
AUC _{BR}	-0.09	-0.59*	-0.56*
Resistance	-0.74**	-0.86**	-0.77**
Resistance elbow extension			
AUC _{BB}	0.11	0.66**	0.62**
AUC _{BR}	-0.18	0.59*	0.45
Part 2			
Parameter	Rater 1	Rater 3	Rater 4
Velocity knee flexion			
AUC _{RF}	-0.50*	-0.56*	-0.53*
AUC _{VL}	-0.64**	-0.61**	-0.52*
Resistance	-0.75**	-0.79**	-0.41
Resistance knee flexion			
AUC _{RF}	0.24	0.65**	0.43
AUC _{VL}	0.36	0.70**	0.25

* $p < 0.05$

** $p < 0.01$

Abbreviations: AUC, area under the curve; BB, Biceps Brachii; BR, Brachioradialis; RF, Rectus Femoris; VL, Vastus Lateralis.

Table 5 shows the results of linear mixed model analysis. None of the parameters AUC_{muscle}, Resistance or Velocity appeared significantly associated with AS. However, the factor Rater significantly affected the AS outcome ($p < 0.05$). The model explained 34% of the variance in AS of the elbow flexor muscles.

Table 5: Linear mixed model with AS score of elbow flexors as dependent variable (part 1)

Parameter	Estimate	Std. Error	df	t	Sig.	95% CI
Intercept	1.111	0.735	41.352	1.511	0.138	-0.374 – 2.596
AUC_{BB}	-0.003	0.008	18.822	-0.397	0.696	-0.019 – 0.013
AUC_{BR}	-0.001	0.004	29.324	-0.252	0.803	-0.008 – 0.006
Resistance	0.011	0.006	38.591	1.924	0.062	-0.001 – 0.022

Velocity	-0.010	0.005	33.875	-1.867	0.071	-0.020 – 0.001
Rater = 1	0.706	0.348	38.895	2.028	0.049	0.002 – 1.410
Rater = 2	1.257	0.298	37.750	4.217	0.000	0.653 – 1.860
Rater = 3	0	0

Abbreviations: AS, Ashworth Scale; Std, standard; df, degrees of freedom; Sig, significance; CI, confidence interval; AUC, area under the curve; BB, Biceps Brachii; BR, Brachioradialis.

Part 2 (Knee extensor muscles)

The negative correlation between AS and Velocity was marked and statistically significant for each of the three raters (see table 3). Table 4 shows a marked and statistically significant negative association between Velocity and Resistance, except for rater 4. The negative association with muscle activity of the knee extensors was moderate and statistically significant in all cases.

Table 6 shows the results of linear mixed model analysis for the knee extensor measurements: Resistance and Velocity were significantly associated with AS, while AUC_{RF} and AUC_{VL} were not. However, the factor Rater showed a highly significant association as well ($p < 0.001$). This model explained 65% of the variance in AS of the knee extensors.

Table 6: Linear mixed model with AS score of knee extensors as dependent variable (part 2)

Parameter	Estimate	Std. Error	df	t	Sig.	95% CI
Intercept	0.670	0.435	43.090	1.539	0.131	-0.208 – 1.548
AUC_{RF}	0.007	0.007	42.198	1.024	0.312	-0.007 – 0.021
AUC_{VL}	0.126	0.131	46.037	0.960	0.342	-0.014 – 0.389
Resistance	0.010	0.002	25.623	4.136	0.000	0.005 – 0.014
Velocity	-0.010	0.003	43.964	-3.593	0.001	-0.015 – -0.004
Rater = 1	1.042	0.227	41.740	4.581	0.000	0.583 – 1.501
Rater = 3	1.079	0.230	41.635	4.702	0.000	0.616 – 1.542
Rater = 4	0	0

Abbreviations: AS, Ashworth Scale; Std, standard; df, degrees of freedom; Sig, significance; CI, confidence interval; AUC, area under the curve; RF, Rectus Femoris; VL, Vastus Lateralis.

DISCUSSION

This is the first study investigating both the construct validity and the inter-rater reliability of the Ashworth Scale, using real-time sEMG and dynamometry recordings. The results of this study show that the methodological characteristics of AS are unsatisfactory for the assessment of spasticity.

Construct validity

The contribution of muscle activity parameters, representing involuntary muscle activity when the muscle is stretched, on the variability in the AS score appeared to be low, in particular in the elbow flexor muscles. The association between the AS and Resistance was generally stronger than the association between AS and AUC_{muscle} . This finding is in agreement with most other studies, [7] however, a recent study on the agreement between various measures of spasticity [23] found no consistent relationship of biomechanical measures with the MAS. In the same study, sensitivity of the MAS, when compared with sEMG outcomes, was low.

In present study, the association between Resistance and AUC_{muscle} was not strong either, indicating that even objectively measured resistance is not a good representation of reflex muscle activity. Resistance was calculated as force-time integrals, instead of the more commonly used slope of the force-angle curve.[24] Force-time integrals are influenced by the duration of joint rotation, which was assumed to be one of the features that contributed to the eventual score for resistance perceived by the individual rater. Remarkable is the large inconsistency between raters. It appeared that the large variation in angular velocity within and between raters, which was associated highly with both AS and Resistance, acts as a confounder in AS assessment.

The results of our study differ significantly from the study of Sköld et al.,[25] who recorded sEMG while scoring the MAS of knee flexors and extensors in SCI patients. Although comparison with present study is problematic due to difference in measurement procedures, they found the majority of sEMG parameters to be strongly associated with the MAS. However, 50% of the measurements in the study were rated as MAS scores '0'. For calculation of the Spearman rank correlation coefficient, these scores all become assigned to the same rank, causing misleading results and overestimation of the association.

Reliability

There is little consensus in literature and among statisticians about what statistical methods are best to analyze rater agreement.[6] The overall agreement between raters gives a general idea about the agreement of the individual scores in the same patient group. In this study rather low values, up to maximum 53%, were found. The kappa coefficient was very low in both upper and lower limb measurements. However, the kappa coefficient can be considered less appropriate for this study, because it is very stringent for a scale with five categories.[21] A weighted kappa, which takes partial agreement into account, could have been used. It is, however, exactly identical to the intraclass correlation coefficient, when the most commonly used weighing scheme is applied.[21] The ICC for absolute agreement between three raters was 0.58, for AS scoring of elbow flexors, and 0.63, for AS scoring of knee extensors. However, overestimation of the ICC is a major problem when the between-subjects variance is high,[26] which is likely in this study population. Another limitation of using ICC is that it assumes equal spacing between categories, which is probably not the case in the AS.

Several explanations can help to understand the findings in this study. Most importantly, raters may differ in defining the specific rating levels of the AS or in the definition of the measured construct itself (i.e. spasticity, or perceived resistance against passive movement). The actual rating levels of the AS (0 to 4) can be viewed as an arbitrary categorization of the underlying construct spasticity, which is a continuous trait. The perceived resistance to passive movement is an aggregate composed of various physical features and weights attached to each feature. Raters may vary in terms of which feature they notice and the weights they associate with each. This is well illustrated by the results of this study. As was shown in table 2, the movement characteristics of the rotations differed largely between and within raters. The differences between raters were shown to play a significant role in the eventual AS score, which gives ground for stratified presentation of the results per rater. There is no standard on how much reliability is ‘good enough’.[21] Anyhow, an ICC of 0.63 can be considered insufficient for use in scientific research, in particular when used as single outcome measure (e.g. [27]). When the test is used for individual judgement, even higher reliability is required.[21]

Study limitations

For the assessment of the contribution of each variable to the AS, we used a linear mixed model. This model assumes that the dependent variable is a continuous variable, which is not the case for AS. In addition, sample size for the study was rather small. Nevertheless, for illustration purposes only we considered the model sufficiently robust.

Although there is some heterogeneity in our population, there is no reason to assume that the nature of the upper motor neuron lesion influences the results in this cross-

sectional study, although it might have increased the between-subjects variance.

Finally, in the upper limb study some additional error might have been introduced by the fact that gravitational force opposed elbow extension during the first part of the movement and assisted during the second part. In the lower limb study this effect was reduced due to limb rotation in the horizontal plane. In addition, the brachialis muscle, another important elbow flexor, was not measured with sEMG due to its deep position.

In summary, the results of this study show that the methodological characteristics of AS are unsatisfactory and that AS should not be used as single outcome measure for the assessment of spasticity. It is essential that both researchers and clinicians are very well aware of the limitations of this scale.

CONCLUSION

Ashworth Scale outcomes appeared to be poorly related to simultaneously measured reflex muscle activity. In its current form the Ashworth Scale is therefore insufficiently valid and reliable as a measure for spasticity. We should therefore stop using it as single outcome measure and focus on newer and promising methods, preferably including sEMG application.

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Competing interests

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Figure 1: Example of sEMG, knee angle and dynamometry output during measurement of a patient with Hereditary Spastic Paraparesis, measured by rater 1. The goniometry signal between the vertical lines correspond to the two consecutive fast knee flexion movements and represent the stretch phase of the knee extensor muscles.





