ORIGINAL ARTICLE

Reliability of the Tardieu Scale for Assessing Spasticity in Children With Cerebral Palsy

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Objective: To measure the Tardieu Scale's reliability in children with cerebral palsy (CP) when used by raters with and without experience in using the scale, before and after training.

Design: Single-center, intrarater and interrater reliability study.

Setting: Institutional ambulatory care.

Participants: Referred children with CP in the pretraining phase (n=5), during training (n=3), and in the posttraining phase (n=15).

Interventions: The Tardieu Scale involves performing passive muscle stretch at 2 velocities, slow and fast. The rater derives 2 parameters; the Spasticity Angle X is the difference between the angles of arrest at slow speed and of catch-and-release or clonus at fast speed; the Spasticity Grade Y is an ordinal variable that grades the intensity (gain) of the muscle reaction to fast stretch. In phase 1, experienced raters without formalized training in the scale graded elbow, knee, and ankle plantar flexors bilaterally, without and with a goniometer. In phase 2, after training, the experienced and nonexperienced raters graded the same muscles unilaterally.

Main Outcome Measures: Intrarater and interrater reliability of the Tardieu Scale.

Results: After training, nonexperienced raters had mean ± SD intrarater and interrater agreement rates across all joints and parameters of 80%±14% and 74%±16%, respectively. For experienced raters, intrarater and interrater agreement rates before training were 77%±13% and 66%±15%, respectively, versus 90%±8% and 81%±13%, respectively, after training ($P<.001$ for both). Specific angle measurements at the knee were less reliable for the angles of catch measured at fast speed. Across all joints, agreement rates were similar using visual or goniometric measurements.

Conclusions: Both parameters of the Tardieu Scale have excellent intrarater and interrater reliability when assessed at the elbow and ankle joints of children with CP, with no difference noted between visual and goniometric measurements. Angle measurements were less reliable at the knee joints. Training was associated with a highly significant improvement in reliability.

Key Words: Cerebral palsy; Muscle spasticity; Rehabilitation.

TARDIEU'S CLINICAL AND physiologic observations in the 1950s[1] and the confirmatory studies by Burke et al[2] emphasized the exaggeration of the velocity-dependent muscle reactions to stretch as a common denominator in patients with paresis caused by damage to the central motor pathways. In 1979, Lance[3(p485)] proposed a definition of spasticity as a "motor disorder characterized by a velocity dependent increase in tonic stretch reflexes (muscle tone), with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome." In simple terms, spasticity was defined as an increase in velocity-dependent responses to phasic stretch.[4]

Tools such as the Ashworth Scale[5] and the Modified Ashworth Scale[6] have been used in clinical trials under the assumption that they measure spasticity. However, it is now established that these instruments evaluate a combination of soft tissue contracture and spastic dystonia, in addition to spasticity itself.[7-10] Based on his detailed observations of muscle response to stretch in CP, Tardieu[11,12] created a clinical method to specifically measure spasticity, which was based on comparing the threshold angles of muscle reaction to stretches at several predefined velocities. Working from the initial modifications by Held and Pierrot-Deseilligny,[13] we have simplified and transformed Tardieu's clinical method into a scale easily usable by the clinician. We have termed this scale the Tardieu Scale.[14-16] The scale rates spasticity as the difference between the reactions to stretch at Tardieu's 2 extreme velocities, the slowest and the fastest possible speed of stretch for the examiner.[11-16] The slow velocity of the first stretch remains below the threshold for any significant stretch reflex and provides an assessment of the passive range of motion. In contrast, the stretch at fastest velocity maximizes the involvement of the stretch reflex. If any spasticity is present, the clinician during this fast stretch encounters a sensation of catch-and-release, or of clonus, fatigable or not, depending on the amount of spasticity.[17]

The current and future therapies administered to patients with spasticity require reliable instruments to evaluate out-

List of Abbreviations

CP	cerebral palsy

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come. In contrast to spastic co-contraction and spastic dystonia, which can be qualitatively assessed but not quantified at the bedside, spasticity might be the only type of muscle overactivity amenable to clinical quantification, if a specific spasticity rating scale is shown to be reliable.[4] We report here on a 2-phase reliability study of the Tardieu Scale in children with CP. The first protocol assessed the intrarater and interrater reliability of the Tardieu Scale using raters with prior experience but no formal training in the use of the scale. The second protocol assessed reliability after a 1-day training course for nonexperienced raters and raters with experience in using the scale. Additionally, we compared the reliability of measurements of spasticity angles without and with a goniometer.

METHODS

Participants

We organized our study in 2 phases (fig 1). Both addressed the reliability of the Tardieu Scale, examining the influence of (1) experience with the scale and (2) a training session on the use of the scale. Each phase of this work constituted an independent protocol that was approved by the Institutional Review Board of the University of Texas Southwestern Medical Center and the Research Advisory Panel of Texas Scottish Rite Hospital for Children. Convenience samples of 5 children with CP for the first phase of the study and 15 children for the second phase were recruited from the neurology clinic at Texas Scottish Rite Hospital for Children. Three additional children were recruited for the 1-day training session conducted before the second phase. Parents signed the institutional review board-approved informed consent, and children 10 years and older signed an assent form.

The participants in the first phase of the study were 3 boys and 2 girls with CP, with a mean age of 10 years (range, 6–17y). Two had diparesis, 2 had quadriparesis, and 1 had hemiparesis. The participants in the second phase were 7 boys and 8 girls with a mean age of 8 years (range, 4–15y). Five had diparesis, 2 had triparesis, 5 had paraparesis, and 3 had hemiparesis. For both phases of the study, each of the enrolled children met the following inclusion criteria: English speaking (to communicate instructions and enhance patient cooperation) and of any ethnic background, aged 3 to 18 years, with spasticity in at least 1 hemibody due to CP. Exclusion criteria were as follows: (1) behavioral or cognitive impairment likely to interfere with the ability to cooperate with the study; (2) severe pain in the limb to be assessed due to cutaneous or joint pathology, making spasticity measurements impossible; (3) significant choreoathetosis affecting the limb to be tested, preventing true muscle rest; (4) cast on the affected hemibody; (5) current treatment by intrathecal baclofen pump; (6) orthopedic surgery on the limb to be assessed less than 6 months before enrollment; (7) prior selective dorsal rhizotomy; (8) initiation or dose change of oral antispasticity drug treatment within 30 days of the study; and (9) botulinum toxin (type A or B) injections less than 90 days before enrollment.

Raters and Procedures

The 6 examiners included 1 physical therapist, 1 developmental pediatrician, 1 pediatric physiatrist, 1 adult neurologist, and 2 pediatric neurologists. Three of the examiners had prior

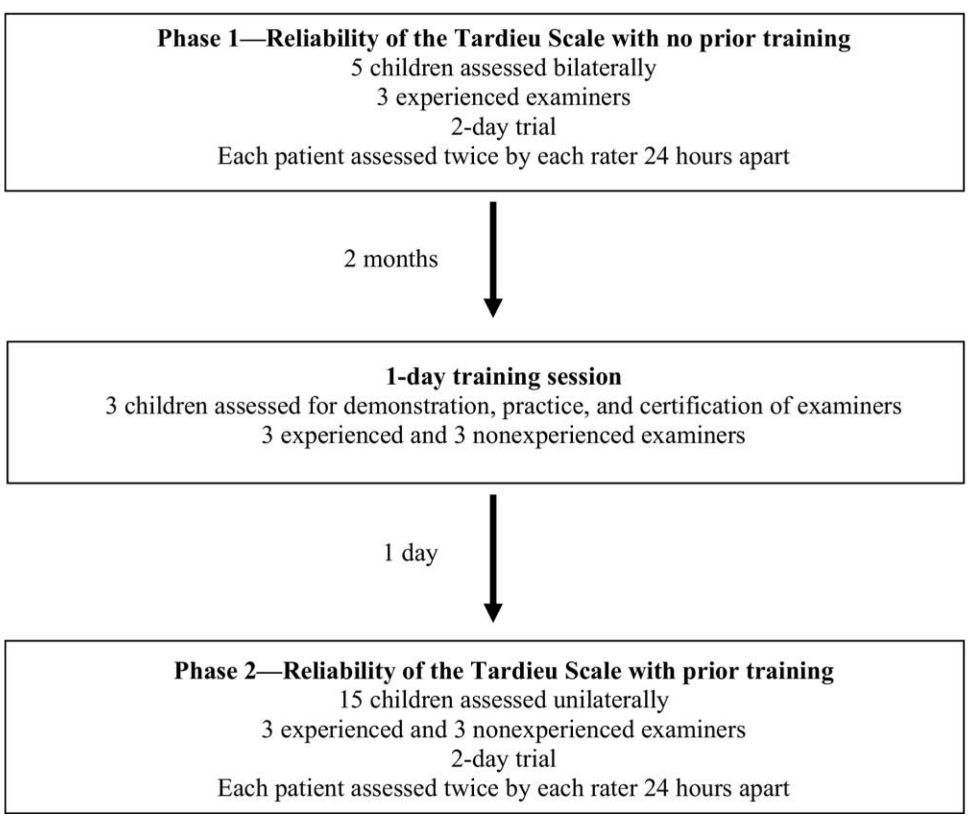

Fig 1. Flow diagram of the 2-phase study.

experience in using the Tardieu Scale; they were the only ones participating in the first phase of the study. The other 3 examiners had no experience in using the scale, and in fact did not know how to use it before entering the training session and the second phase of the study. All 6 examiners participated in the second phase, in which all received the same formal 1-day training before performing the spasticity ratings, which also constituted a teaching of the scale for the 3 inexperienced raters. Each phase of the study involved a 2-day trial, in which each patient was assessed twice by each rater 24 hours apart. The order of patient assessments was randomized, and raters were not to discuss findings until study completion.

In the first phase of the study, spasticity was measured bilaterally in the elbow flexors, knee flexors, and ankle plantar flexors (ie, 6 joints per patient). In the second phase, spasticity was measured in the same muscles unilaterally (on the side determined as being the more affected)—that is, 3 joints per patient. The angles of arrest at slow speed and of catch-and-release or clonus at fast speed were assessed first using visual estimates and then using a goniometer. Each examiner performed all spasticity ratings alone (ie, without help from another person), including the goniometric measurements. All assessments were to be completed within 15 minutes for each patient. In each examination room a monitor supervised the assessments, ensured patient and caregiver comfort, and verified proper completion of the case report forms. To allow retrospective qualitative comparisons between examination techniques, assessments were videotaped.

Procedures Involved in the Tardieu Scale

The Tardieu Scale measures spasticity using 2 parameters: the spasticity angle X and the spasticity grade Y. The spasticity angle X is the difference between the angles of arrest at slow speed and of catch-and-release or clonus at fast speed, whereas the spasticity grade Y is an ordinal variable that grades the intensity and thus measures the gain of the muscle reaction to fast stretch.

Appendices 1 and 2 provide an outline of the Tardieu Scale, on which we elaborate here.

Stretch velocity (appendix 1). The extremity to be measured should be comfortably resting before execution of the muscle stretch. The Tardieu Scale involves 2 stretch maneuvers, one at a slow speed (velocity V1) and one at the fastest speed possible for the examiner (velocity V3).

V1 is "as slow as possible" for the examiner. V1 measures the range of passive motion. During a slow stretching movement, the examiner determines the angle of movement arrest, either due to patient discomfort or a mechanical resistance that could not be overcome without jeopardizing the integrity of the joint.

V3 is "as fast as possible" for the examiner. In some cases, the Tardieu Scale may also use V2, which is the velocity of the limb segment naturally falling under gravity (see appendix 1). V2 is only practical for knee extensors, wrist extensors, and elbow flexors in severely paretic patients and was not evaluated in the current study.

Grading of the stretch reflex (appendix 2). The grading generates 2 variables, X and Y.

X is the spasticity angle, which measures the position threshold for the stretch reflex. All angles are measured relative to the muscle tested (not according to anatomic principles), such that 0° is defined as the position of minimal stretch of the muscle (eg, when assessing plantar flexors, the angle 0° corresponds to an imaginary fully plantar-flexed position of the ankle) (fig 2). After determining the angle of arrest at slow speed of stretch (ie, X_{V1} or range of passive motion), the examiner determines the threshold angle of catch-and-release or clonus at fast speed (X_{V3}). The difference ($X_{V1} - X_{V3}$) is the spasticity angle (X), which reflects only the velocity-dependent stretch reflex. The larger the spasticity angle, the more spastic the muscle. By definition, in cases where there is no palpable catch or clonus at fast speed (spasticity grade Y=0 or 1, see below), no angle of catch is specified, and the spasticity angle is then given the value 0 (ie, $X_{V1}=X_{V3}$) for statistical analysis.

Y is the spasticity grade, which is an ordinal variable grading the intensity and thus measuring the gain of the muscle reaction to fast stretch (V3). The phenomenon described in each grade corresponds only to muscle contraction induced by stretch

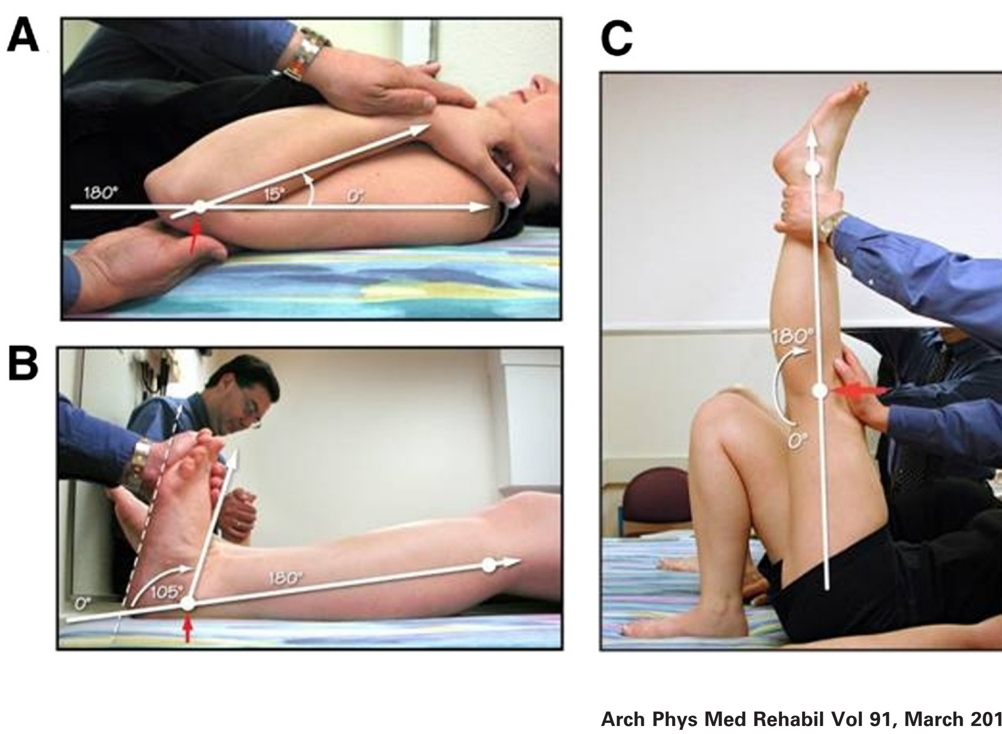

Fig 2. Angles used in the Tardieu Scale. Zero is the theoretical position of minimal stretch of the muscle to be assessed. For the elbow flexors (A), for the ankle plantar flexors (B), and for the knee flexors (C).

reflex; it cannot represent contracture or inadvertent voluntary contraction, in contrast to other scales that have been assumed to measure spasticity.[5,6]

Grade 0: A "catch" not followed by release that consistently occurs at the end of the range of passive motion. It represents absent spasticity.

Grade 1: Mild resistance slowing down the passive movement without complete interruption. It is likely due to a motor neuron pool discharge that is not sufficiently synchronized to generate an opposing force matching that of the examiner.

Grade 2: Transient interruption of the passive movement (catch and release). This likely reflects a stronger motor neuron discharge, sufficiently synchronized to generate an opposing force temporarily matching that of the examiner (catch). The discharge then decreases, allowing passive movement to resume (release). This release is likely due to (1) the preceding movement interruption that has brought the stretch velocity close to 0, thus removing the main stimulus of the response; and (2) inhibitory reflexes involving group III and IV fibers.[18] In cases where the catch is not followed by obvious release but occurs repeatedly at a consistent angle less than the passive range of motion, it is still accepted as angle of catch-and-release, and the grade Y is considered 2.

Grades 3 and 4: Severe spasticity. When the release occurs at a speed that is itself faster than the velocity threshold of the stretch reflex, it triggers a new stretch reflex and thus a clinical sensation of recatch. After the recatch comes a rerelease, which in succession is termed clonus.

Nonratable describes a catch not followed by obvious release that occurs at inconsistent angles upon repeat testing. This may correspond to inadvertent voluntary contractions or to nonspastic dystonia. The spasticity is deemed nonratable (no value for grade Y).

Position of Other Limb Segments During Assessments

To assess elbow flexors, the upper arm was maintained parallel to the supine body (shoulder flexion angle 0^o). To assess ankle plantar flexors, the knee was maintained flexed at 45^o (a technique that mostly assesses soleus spasticity). To assess knee flexors, the hip was maintained flexed at 90^o (with contralateral hip and knee resting on a bolster in a flexed position).

Statistical Analysis

We assessed the reliability of the 2 parameters of the Tardieu Scale by calculating the frequency of agreement between assessments (table 1). Agreement was measured using the absolute value of actual differences between measurements. For the parameters X_{V1}, X_{V3}, and their difference X, agreement was defined as an absolute difference equal to or less than 10°, close to about 10% of the normally available range of motion, a difference that was deemed of no clinical significance. Agreement between 2 values for the parameter Y was defined as a difference of zero. We also calculated the actual mean, minimum, and maximum ratings and mean intra- and interrater differences of joint angle measurements for raters with and without experience after standardized training (table 2).

For each phase of the study, the absolute differences between the day 1 and day 2 readings by the same rater were used to compute intrarater reliability. Intrarater reliability of the scale was computed as the mean rate of agreement between the 2 readings of all raters. Interrater reliability was computed as the mean rate of agreement between readings made on the same patient by all pairs of raters, averaged over all of the subjects. The level of agreement was defined as good if between 70% and 85%, and excellent if above 85%.

Significance tests involving comparisons of the mean rate of agreement for a given parameter at a given joint between the 2 different groups of raters (experience vs no experience) were performed using a Fisher exact test. To compare the results for the same raters across studies, the McNemar test was used. We averaged intrarater and interrater agreement rates over all joints and parameters, in experienced raters without and with formal training, and in inexperienced raters with formal training, using the method of the sample mean and the sample variance. Comparisons of mean agreements averaged across all joints and parameters are shown at the bottom of table 1 and were performed using paired (training vs no training) and 2-sample (experience vs no experience) *t* tests using the SAS/STAT version 9.1 program package.[a]

RESULTS

Experienced Raters Without Formal Training (First Phase of the Study)

Averaged over all joints and parameters, the combined mean ± SD intrarater agreement rate for experienced raters without formal training was 77%±13%, while the interrater agreement rate was 66%±15% (see table 1). Specifically, for the angle measurements (X_{V1}, X_{V3}, X), the intrarater agreement rate was good to excellent except at the knee for X_{V3} and X. The interrater agreement rate was good to excellent for all angle measurements at the elbow, but not at the ankle and the knee. The agreement rate was equivalent whether estimating angles visually or using a goniometer. The spasticity grade Y had good to excellent intrarater and interrater agreement rates regardless of the joint.

After Formal Training (Second Phase)

After training, nonexperienced raters had mean ± SD intrarater and interrater agreement rates across all joints and parameters of 80%±14% and 74%±16%, respectively, whereas experienced raters had intrarater and interrater agreement rates of 90%±8% and 81%±13%, respectively ($P<.001$) (see table 1). Therefore, after formal training, across all joints and parameters, intrarater and interrater agreement rates were good to excellent, ranging from 74% to 90%. The measure of the passive range of motion (X_{V1}) had good to excellent intrarater and interrater agreement rates for whichever joint was considered. The intrarater and interrater measures of the angle of catch-and-release at fast speed (X_{V3}) and of the spasticity angle (X) were good to excellent at the elbow and ankle. Again, agreement rates were lower for X_{V3} and X in the knee flexor assessments, for the angles of catch measured at fast speed, as well as in the ankle plantar flexors for the nonexperienced raters. As seen in table 1, intrarater and interrater agreement rates were similar using visual or goniometric angle estimations. Table 2 confirms the lower reliability of the fast speed measurements X_{V3} and X in the knee flexors.

All agreement rates between visual and goniometric estimates for X_{V1} or X_{V3} were over 90% (data not shown). The spasticity grade Y again had good to excellent intrarater and interrater agreement rates for whichever joint was considered.

DISCUSSION

This 2-phase, pretraining and posttraining, intrarater and interrater agreement study of the Tardieu Scale shows good to excellent intrarater and interrater reliability (yielding >70% agreement between measures) across all joints and all parameters in 2 key muscle groups in children with CP: the elbow flexors and the ankle plantar flexors. Reliability was lower for the angle measurements in the knee flexors. The study also shows that 1 day of formal training greatly enhances reliability, more so than prior

Table 1: Tardieu Scale Intra- and Interrater Agreement Rates for Experienced Raters With and Without Standardized Training and Inexperienced Raters With Standardized Training

	Intrarater			Interrater		
	No Training	Training		No Training	Training	
	Experience	Experience	No Experience	Experience	Experience	No Experience
Ankle						
Visual						
Xv1	87	97	87	63	96‡	82‖
Xv3	80	91	85	65	78	63
X	73	85	88	64	79	63§
Goniometric						
Xv1	80	92	89	54	87‡	89
Xv3	73	97†	92	62	87*	81
X	74	88	81	48	79†	69
Y	87	79	65	80	86	73§
Elbow						
Visual						
Xv1	97	97	100	95	91	100§
Xv3	80	97†	87	76	86	82
X	80	97†	85	79	90	79
Goniometric						
Xv1	94	100	100	90	86	99‖
Xv3	72	100‡	85§	68	82	78
X	72	97‡	85	68	95‡	78‖
Y	83	87	72	67	95‡	90
Knee						
Visual						
Xv1	72	82	76	50	71	76
Xv3	49	77†	52§	43	65*	44§
X	52	74†	52	57	54	44
Goniometric						
Xv1	76	85	95	52	78*	84
Xv3	62	85*	61§	54	68	52
X	73	82	58§	55	54	47
Y	97	95	79	97	95	75¶
Mean	76.8	89.7	79.7	66.0	81.0	73.7
SD	12.5	8.0	14.5	15.3	12.6	16.4
Training vs no training#		$P<.001$			$P<0.001$	
Experience vs no experience#			$P=0.009$			$P=0.11$

NOTE. Agreement was defined as an absolute difference equal to or less than 10 degrees.
Agreement frequency (%) is indicated for each parameter for ankle plantar flexor, elbow flexor, and knee flexor assessments; X_{V1}, X_{V3}, and X ($X_{V1}-X_{V3}$), as in text. All ratings were performed first using visual estimates and then goniometric measurements. See Appendices for further details.
*$P<0.05$, †$P<0.01$, ‡$P<0.001$ (comparisons no training to training, McNemar test).
§$P<0.05$, ‖$P<0.01$; ¶$P<0.001$ (comparisons no experience to experience, Fisher exact test).
#Degrees of significance *P* of comparisons training vs no training (paired *t* test), and experience vs no experience (2-sample *t* tests) all joints and parameters combined.

personal experience in using the scale. The improvement in reliability was particularly evident in the assessments of the angle of catch at fast speed X_{V3} (see table 1), with the exception of X_{V3} in the knee flexors. Thus, a training session makes the Tardieu Scale a more reliable instrument for the measurement of spasticity at the elbow and ankle in children with CP. We found no difference in reliability between visual and goniometric assessments, indicating that the Tardieu Scale can reliably be administered without the use of a goniometer.

Clinical Relevance of a Tool to Measure Spasticity

Most studies of clinical spasticity measurement and treatment of spastic paresis have consistently used the Ashworth Scale, an instrument measuring tone or stiffness, that became a de facto criterion standard before conceptual or methodological validation occurred. This article provides the first full description of the Tardieu Scale, which we have developed and named from Tardieu's clinical method,[11,12] working after Held and Pierrot-Deseilligny's initial modifications.[13-16] A simple clinical tool for specific spasticity measurement may have practical and theoretical importance, as the therapies administered to patients with spastic paresis require reliable instruments to evaluate outcome. A positive correlation appears to exist between the degree of spasticity and other forms of stretch-sensitive overactivity, such as spastic co-contraction, as well as with functional impairment.[19,20] Thus, a clinical marker of stretch sensitivity like spasticity may be useful to predict the severity of co-contraction during movement in spastic paresis.[4] In practice, the Tardieu Scale makes spasticity the only type of muscle overactivity easily quantifiable at the bedside, in contrast to spastic co-contraction and spastic dystonia.[4] This tool has been successfully used to quantify clinical effects of antispastic treatments.[14,16]

Table 2: Tardieu Scale Mean, Minimum, and Maximum Ratings and Mean Intrarater and Interrater Differences of Joint Angle Measurements for Raters With and Without Experience After Standardized Training

	Mean	Minimum	Maximum	Intrarater Mean Difference	Interrater Mean Difference
Ankle					
Visual					
X_{v1}	100	70	150	5.3	7.2
X_{v3}	80	40	130	6.1	8.5
X	22	0	55	6.8	8.9
Y	2.6	1	4	0.3	0.4
Goniometric					
X_{v1}	102	75	150	5.8	7.1
X_{v3}	80	50	120	4.9	6.3
X	24	0	65	7.0	8.4
Y	2.6	1	4	0.3	0.4
Elbow					
Visual					
X_{v1}	180	155	195	2.4	3.7
X_{v3}	168	70	190	7.3	13.1
X	12	0	105	5.7	10.7
Y	0.9	0	2	0.2	0.4
Goniometric					
X_{v1}	180	165	195	2.1	4.2
X_{v3}	169	70	195	5.8	12.5
X	11	0	105	4.4	9.1
Y	0.9	0	2	0.2	0.4
Knee					
Visual					
X_{v1}	144	85	175	7.5	11.0
X_{v3}	114	50	175	11.8	13.9
X	30	0	80	12.1	15.0
Y	2	0	3	0.1	0.2
Goniometric					
X_{v1}	140	90	175	6.0	9.0
X_{v3}	114	60	170	9.4	12.1
X	27	0	75	9.0	14.4
Y	2	0	3	0.1	0.2

NOTE. X_{V1}, X_{V3}, and X represent degrees of ROM. Y is an ordinal variable grading spasticity. See Appendices for further details.

Statistical Method of Measuring Reliability

The goal of this study was to answer 2 questions: "How often does a rater obtain the same results when looking at 1 patient on 2 occasions?" (intraobserver agreement rate) and "How often do 2 raters get the same result when observing the same patient?" (interobserver agreement rate).

As the kappa coefficient and the intraclass correlation coefficients are dependent upon the homogeneity of the subjects used in a study,[21-23] they are both meaningful as comparative statistics (ie, to compare the reliabilities of different tools used by the same group of raters on a similar group of subjects).[24] This was not the purpose of this study. To be clinically relevant we have opted to report the percentage of exact matches and/or the percentage of matches within x units. We have also displayed the actual mean intrarater and interrater differences of joint angle measurements for all raters.

Previous Literature on the Reliability of the Tardieu Scale

A number of studies have mentioned or used the Tardieu Scale for rating spasticity since the description of the scale.[14] Some of these studies have used what has been called a "Modified Tardieu Scale," from our early personal communication on an unfinished version of the instrument, lacking in particular the spasticity grading Y and the definition of the spasticity angle ($X_{V1} - X_{V3}$).[25]

At least 5 of these studies[26-30] have looked at the reliability of the Modified Tardieu Scale, with inconsistent conclusions, all having used intraclass correlation coefficients or kappa statistics. Ours is the first study that tests the reliability of the complete Tardieu Scale and uses percent agreement frequency as the statistical method of reference. Of note, there have been 4 studies looking at the validity of the scale. In particular, Patrick and Ada[10] show strong construct validity of the Tardieu Scale as compared with an electromyographic measure of muscle reaction to fast stretch. Other studies[31-33] have tested the validity of the Modified Tardieu Scale versus functional assessments.

Training Versus Experience in Using the Scale

This study shows how 1 day of formal training markedly enhanced reliability. Experience yielded a less impressive increase in intrarater reliability only. To the experienced raters, the 1-day training was a means for them to use the scale in a more homogeneous manner (anatomic landmarks, patient and limb positions, relaxation techniques, etc). To the inexperienced raters, the 1-day training was also the way of learning how to use the scale. The improvement in reliability with training was particularly evident in the assessments of the angle of catch X_{V3} (see table 1). However, experience specifically improved interrater reliability for the spasticity grade Y in the ankle plantar flexors and knee flexors, where nonexperienced raters had some difficulty. Combining formal training and experience might lead to improved reliability in general, and in particular for the assessment of the angle of catch X_{V3} at the knee flexors. Finally, the data suggest that the reliability of spasticity angle assessments is higher when using the same rater versus different raters. However, training of experienced raters provides a reliability improvement that renders their interrater reliability comparable to the intrarater reliability of inexperienced raters. This may be relevant in research settings, in cases where sequential assessment by the same rater is not possible.

Lower Reliability at the Knee Flexors

The difficulty achieving interrater agreement for X_{V3} at the knee may have several sources. First, the Tardieu Scale measures angles relative to the muscle that is stretched, the angle 0° being defined as the position of minimal stretch of the muscle (eg, the "hamstrings angle" would be 0° with the knee fully flexed and 180° when the knee is fully extended). This may have confused the raters accustomed to traditional anatomic angles (knee extended, 0°; knee fully flexed, close to 180°). This potential issue may be resolved by specifically reviewing the 0° angle for each muscle of interest in the training session. Second, some raters who encountered a catch not followed by obvious release did not repeat the maneuver. These raters may have rated spasticity grade 2 by considering their first angle of catch as X_{V3}, as opposed to nonratable spasticity if the angle of catch was inconsistent (see Methods section). Third, the fastest velocity, V3, is intrinsic to the examiner. This potential source of disagreement may be insensitive to training sessions. Finally, in larger children or teenagers, some examiners may experience difficulty in performing rapid knee extension, which also might impact interrater reliability.

CONCLUSIONS

The Tardieu Scale has good to excellent intrarater and interrater reliability in both angle and grade parameters when measuring elbow flexor and ankle plantar flexor spasticity in children with CP, a reliability level that is improved by a 1-day formal training. While the Tardieu spasticity grade (Y) assessment is also reliable when measuring knee flexor spasticity, spasticity angle measurements X_{V3} and X in that muscle group are less reliable, even after a 1-day training. Experience in using the scale does not have as significant an impact as standardized training. We recommend standardized training in using the scale for both experienced and nonexperienced raters because it may considerably enhance reliability, particularly in the measurements of angles of catch at fast speed. Training material has been developed in conjunction with this study and will be published separately.

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APPENDIX 1: THE TARDIEU SCALE: PRINCIPLES

Grading always performed:

- On a muscle at rest before the stretch maneuver
- At a reproducible velocity of stretch. Once the fast velocity is selected for a muscle, it remains the same for all subsequent tests.
- At the same time of the day
- In a constant body position for a given limb
- Other joints, particularly the neck, must also remain in a constant position throughout the assessment and for all other assessments.

Velocity of Stretch

- SLOW = V1: As slow as possible (slower than the rate of natural drop of the limb segment under gravity)
- FAST = Either V2 or V3
  - V2: Speed of the limb segment falling under gravity
  - V3: As fast as possible (faster than the rate of natural drop of the limb segment under gravity)

APPENDIX 2: THE TARDIEU SCALE: GRADING

X = Spasticity Angle (Threshold)

Angle of arrest at slow speed X_{V1} *minus* Angle of catch at fast speed X_{V3}

Y = Spasticity Grade (Gain)

0. No resistance throughout passive movement
1. Slight resistance throughout passive movement
2. Clear catch at precise angle, interrupting passive movement, followed by release
3. Fatigable clonus (<10s when maintaining pressure) occurring at a precise angle, followed by release
4. Unfatigable clonus (>10s when maintaining pressure) occurring at a precise angle

- Catch without release: graded 0 if $X_{V1}=X_{V3}$; "unratable" spasticity otherwise
- Catch with "minimal" release: graded 2 if X_{V3} is consistent and consistently less than X_{V1}
- Angle 0° = position of minimal stretch of the tested muscle
- For grades 0 and 1, spasticity angle X=0° by definition

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