Reliability of Clinical Evaluators of Spasticity in Patients with Stroke

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RELIABILITY OF CLINICAL EVALUATORS OF SPASTICITY IN PATIENTS WITH STROKE

by

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A capstone project submitted to the Graduate Faculty in Physical Therapy in partial fulfillment of the requirements for the degree of Doctor of Physical Therapy (DPT), The City University of New York

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THE CITY UNIVERSITY OF NEW YORK
ABSTRACT
RELIABILITY OF CLINICAL EVALUATORS OF SPASTICITY IN PATIENTS WITH STROKE

BY

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Spasticity is characterized by hyperexcitable stretch reflexes with amplitude increases in response to velocity dependent passive movement and resistance. Spasticity is the result of abnormal function of segmental and suprasegmental neuronal circuits. The objective of this study was to determine any positive correlation between three clinical evaluators of spasticity (i.e., the pendulum test, the patellar tendon tap test (PTT), and the Modified Ashworth scale) in their reliability to assess spasticity in people post-stroke. It was hypothesized that the use of force movement sensors along with surface electromyography increases the reliability of the standardized clinical tests. The results show that all three clinical tests detected spasticity. However, the pendulum and the patella tendon tap tests were more reliable and sensitive than the Modified Ashworth scale in detecting the varying levels of spasticity in post-stroke subjects. These tests should be used in the clinical setting along with force-movement sensors in order to measure spasticity more accurately.
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**Introduction**

When an upper motor neuron lesion occurs, changes in muscle tone are commonly manifested as spasticity, rigidity, clonus, and/or hyperactive reflexes. Spasticity is characterized by a velocity dependent increase in muscle resistance to passive movement, commonly seen in patients who have had a stroke.\(^1\) Spasticity is also characterized by a velocity dependent increase in the tonic stretch reflexes with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflexes as one component of the upper motor neuron syndrome.\(^2\) It is believed in large part that spasticity is due to the reduction of the spinal inhibitory mechanisms, involving but not limited to reciprocal inhibition between antagonist muscles, and excitability of spinal alpha motoneurons.\(^3\)

Three clinical tests are traditionally used to detect increase in muscle tone. These are the modified Ashworth scale, the pendulum test, and the patellar tendon tap test (PTTT) or hammer test. The most widely test studied is the Modified Ashworth scale. However, there is limited research on its validity in the post stroke population. When assessed against another outcome measure, the Tone Assessment scale and the Modified Ashworth scale held good intra-rater and inter-rater reliability, yet it was not possible to be applied at proximal joints.\(^4\) The intra-rater and inter-rater reliability of the Modified Ashworth scale for the lower limb was poor in other experiments, and the only agreed value was that of 0.\(^5\) One study reported that the Modified Ashworth scale is more effective in detecting muscle hypertonicity rather than spasticity, after the excitability of the alpha motor neurons in patients who have suffered a stroke was assessed.\(^6\)

Although the reliability of the Modified Ashworth Scale in the stroke population is questionable, there has been promising research in the validity of detecting spasticity in the cerebral palsy population with this outcome measure. The Modified Ashworth scale scores were correlated with an isokinetic dynamometer and surface EMG in cerebral palsy patients, yielding higher
correlations to the rate of change in resistance and onset angle of stretch, especially in the quadriceps muscle.\textsuperscript{7}

Another clinical test used to assess the increase in muscle tone post-stroke is the pendulum test. Wartenberg described the pendulum test as the movement of the leg following its drop from a horizontal position while subjects are instructed to relax. The Wartenberg pendulum test has been shown to differentiate spasticity and rigidity using a relaxation index and velocity of the swing.\textsuperscript{8} The video-based pendulum test is considered reliable in detecting abnormal joint motion, such as hypertonicity.\textsuperscript{9} The pendulum test has been studied and compared to objective measures. One study took the pendulum test and compared it to an objective measure, the Polhemus tracking system, in proving the reliability and validity in detecting spasticity in patients who are post stroke, which found this test to have good test-retest reliability.\textsuperscript{10} One other notable study explained that the dropping the limb at different points in the trajectory, altered the results of the pendulum test, based on the velocity dependent thresholds, which was seen on the EMG.\textsuperscript{11}

Concerning the patellar tendon tap test, there is not much research done on its validity in detecting spasticity in the stroke population. One article uses the patellar tendon tap test to assess the electromechanical delay of the reflex response, where the results yielded that the response was shorter in those that had cerebral palsy compared to normal participants.\textsuperscript{12} This finding may infer that test could be used to gauge the response in the stroke population, since there is a hyperexcitability of the stretch reflex as well.

The objective of the present study was to correlate and compare the reliability and sensitivity of the Modified Ashworth scale, the pendulum test, and the patellar tendon tap test in assessing and evaluating spasticity in patients with stroke. We hypothesized that movement-force sensors and
surface electromyography used with the clinical tests improves the reliability and objectivity of these tests. We also hypothesized that all three tests evaluate spasticity similarly in the stroke population.

Methods

Participants

15 participants were recruited through flyers and word of mouth. Of the 15 participants, the control group consisted of 10 subjects (F = 6, M = 4); ages 21 – 29, who were healthy and neurologically intact, with no history of knee involvement including: arthritis, fractures, or any previous knee surgeries. The experimental group consisted of 5 subjects (F = 2, M = 3), over the age of 65, who had suffered a stroke at least 3 – 6 months prior to the experiment, with no history of knee involvement including: arthritis, fractures, or any previous knee surgeries.

Experimental Protocol

Participants sat on a plinth with their lower extremities suspended. The area for the placement of surface electrodes was cleaned with alcohol pads. Two biopac disposable cloth surface electrodes were placed on the Medial Quadriceps (MQ), Lateral Quadriceps (LQ), Semimembranosus (SM), and Biceps Femoris (BF) bilaterally. The ground electrode was placed on the patella. The digital motion sensor was placed on the lateral aspect of the lower leg, spanning from the angle of to the knee. All EMG signals were obtained through the Digitimer D360 8-Channel Amplifier System using a single differential bipolar surface electromyographic.
Once all the electrodes and the sensor were connected to the EMG, the pendulum test, patella tendon tap test, and Modified Ashworth Scale were administered in a random order. For the pendulum test, participants sat on the plinth with their leg extended and held in extension by the tester. With participants relaxed, the tester dropped the leg, allowing it to swing freely until movement oscillations ceased. The number of oscillations was recorded through the movement sensor. During the patellar tendon tap test, participants were asked to be seated in the same manner as above. The tester then struck the subject’s patellar tendon with the reflex hammer. Similar to the pendulum test, the oscillations were counted until they ceased and the muscle activity was recorded by the surface electrodes. The Modified Ashworth Scale test was performed in sitting and prone. Participants were given the same instructions as the other two tests. The tester then moved the limb being tested through its entire range of motion and then performed the same act with increased velocity. If a catch was felt with the test, it was given an appropriate grade of present spasticity based on the scale. All tests were performed at least three times and the results were then averaged. The overall procedure took an hour and a half. In between each test, the participants were given a ten to fifteen minute break. The experimental protocol was approved by the Institutional Review Board (IRB) committee of the City University of the New York.

Data Analysis

All trials were averaged in an Excel file and then the first 6 averaged trials were used for all three tests to run statistical analyses. One-way-ANOVA, t-test, and Pearson correlation tests were used to compare each factor (velocity, amplitude, latency, and hammer force), of each variable (pendulum test, patella tendon tap test, Modified Ashworth scale), between control and
experimental groups respectively. A statistically significant difference was concluded when p-value was less than 0.05.

Results

Pendulum Test

The data showed a difference in the amplitude and velocity of swings between control and experimental subjects. As seen in Figure 1.1, the amplitude of a swing in one healthy participant was different from that of one patient with stroke. Comparison of the movement size of the swings in °/s within the first six swings between healthy participants and participants with stroke also showed a difference, as depicted in Figure 1.2. A one-way-ANOVA comparison of the amplitude of the swings in flexion and extension showed a statistical difference with a p-value of less than 0.05 for the first three swings, while the remaining three swings were not significant with p-values of greater than 0.05. The average of the subjective number of swings in healthy participants was 8, while in patients with stroke, the number was 6; however, no statistical difference was found between the number of swings in healthy participants versus patients with stroke [Figure 1.3]. Similarly, there was a difference found in the velocity of the swings in flexion and extension between healthy participants and patients with stroke [Figure 1.3]. Though, statistically, only the first three swings were considered significant with p-values of less than 0.05 [Figure 1.4].

A comparative EMG analysis of muscle activity between healthy participants and patients with stroke during the pendulum test was also conducted. As seen in Figure 1.5, the LQ and BF were found to have increased activity and the MQ and SM were found to have decreased activity in patients with stroke when compared to healthy participants. However, the one-way-
ANOVA did not yield significant results, as the p-value was greater than 0.05. Additionally, no difference was found in the latency of muscle activation of the LQ, BF, and SM as compared to the MQ [Figure 1.5].

Figure 1.1 depicts a trace recording of the motion sensor in healthy participants vs. patients with stroke in degrees/second (to highlight the differences between number of swings and amplitude of swings between the two groups).

Figure 1.2 depicts the amplitude of each swing in degrees/second.
Figure 1.3 depicts an average of the number of swings in healthy participants vs. patients with stroke.

Figure 1.4 depicts the velocity of each swing during flexion and extension in degrees/second.
Figure 1.5 depicts the activity of each individual muscle during the pendulum test in healthy participants vs. patients with stroke.

**Patella Tendon Tap Test**

Similar to the pendulum test, differences were noted in the amplitude of the swings, as well as the velocity of the swings, between healthy participants and patients with stroke [Figure 2.1-2.4]. Statistical significance was found for the first three swings with the p-value being less than 0.05. Additionally, the hammer force was found to be higher in healthy participants compared to patients with stroke, as seen in Figure 2.3. However, t-test analyses detected no significant relationship between the hammer force and the amplitude or velocity of the swing.
Further analyses of EMG recording of muscle activation during the test showed increased activation of MQ, LQ, and BF in patients with stroke as compared to healthy participants, as seen in Figure 2.5. Additionally, a delayed latency in activation of BF was not found in patients with stroke, instead reciprocal facilitation was evident, as noted by the offset and peak latency depicted in Figure 2.6.

Figure 2.1 shows a trace recording of the motion sensor in healthy participants vs patients with stroke in degrees/second (to highlight the differences in velocity and latency on average between the two groups)

Figure 2.2 depicts the velocity of each swing during flexion and extension in degrees/second
Figure 2.3 shows the amplitude of each swing and the average of hammer force applied in healthy participants vs. patients with stroke during the first 6 trials.

Figure 2.4 shows a trace recording of the motion sensor in healthy participants vs. patients with stroke (to highlight the differences in latency between the two groups).
Figure 2.5 displays an example of individual muscle activation in healthy participants vs. patients with stroke.

Figure 2.6 depicts individual muscle amplitude, offset latency, and peak latency, respectively.

Modified Ashworth Scale

Analysis of quadriceps and hamstring muscle activity showed inconsistencies with respect to amount of muscle activation in comparison to the given subjective scores [As seen in Figure 3.1-3.3]. In Figure 3.1, subject S1 received a subjective score of 1+ and was shown to
have an amplitude of 1.77 mV, whereas subject S4 received a subjective score of 3 and only had an amplitude of .9 mV. Similarly, in Figure 3.2, subject S5 has a much higher amplitude (3.41 mV) than subject S4 (.251 mV), however, subject S5’s subjective MAS score is 1 and subject S4’s is 3. Figures 3.2 and 3.3 show similar discrepancies. A bar graph representing the medial hamstring is not shown, as there was only data recorded for this muscle from one experimental subject marked as having hamstring spasticity, the other subject who was marked as having hamstring spasticity, had too much noise on this muscle's recording and the data was not able to be properly extracted and interpreted.

Figure 3.1 shows a bar graph depicting the amplitude of medial quad muscle activity and the subjective MAS score given to three participants with stroke graded as having quad spasticity.
Figure 3.2 shows a bar graph depicting the amplitude of lateral quad muscle activity and the MAS subjective score given to three participants with stroke graded as having quad spasticity.
Figure 3.3 shows a bar graph depicting the amplitude of lateral hamstring muscle activity and MAS score given to two participants with stroke graded as having hamstring spasticity.

Comparison Graphs

Figures 4.1 and 4.2 show a comparison between the MAS subjective scores and the first swing amplitude of the pendulum test and PTTT, respectively. Inconsistencies can be noted between MAS and the results of the pendulum test and the PTTT. Figure 4.3 compares the second swing amplitude of the pendulum test and the first swing of the PTTT and Figure 4.4 compares the third swing of the pendulum test and the second swing of the PTTT, and although there is no significant relationship between the two in both graphs, a trend can be seen.
Figure 4.1 depicts a scatter plot comparing the first swing amplitude of the pendulum test and the MAS subjective number given for quadriceps spasticity (blue) and hamstring spasticity (orange).

Figure 4.2 depicts a scatter plot comparing the first swing amplitude of the PTTT and the MAS subjective number given for quadriceps spasticity (blue) and hamstring spasticity (orange).
Figure 4.3 depicts a scatter plot comparing the amplitude of the second swing during the pendulum test and first swing during the PTTT in participants with stroke.

Figure 4.4 depicts a scatter plot comparing the amplitude of the third swing during the pendulum test and second swing during the PTTT in participants with stroke.


**Discussion**

**Pendulum Test**

According to Bhakta, reduced reciprocal Ia inhibition and increased co-contraction are associated with spasticity.\(^{13}\) The pathological organization of these neuronal circuits could be potentially contributing to the movement size of swings of the lower limb to be decreased in the participants with stroke when compared to the control participants of this study. In the healthy subjects, reciprocal Ia inhibition is intact. This grants their lower limb to swing freely with a larger amplitude than the participants with stroke, allowing for an increased velocity for the first three swings because the limb can drop from a higher height with no restriction. After the first three swings, control subjects and subjects with stroke begin to take on more similar patterns in amplitude and velocity, as seen in Figure 1.1 and 1.4. This is most likely due to spasticity being velocity dependent, as stated by Lance, so as the speed decreases with each successive swing for those with stroke, the threshold that was initially met to elicit spasticity, is no longer reached, and the limb can swing more like the limb of a healthy subject.\(^2\) Fowler, et al performed a study that used participants with cerebral palsy, and this also showed significant differences between the first swings in the pendulum test between control and experimental subjects.\(^{14}\) Fowler claimed the first swing of this test was the best indicator of the degree of spasticity in subjects with cerebral palsy.

Subjectively, it was observed that on average the healthy participants' lower limb swung eight times, while patients' with stroke swung six times in Figure 1.3. There was no significant difference between these two groups in this category. It was expected that a significant difference would be seen, with the participants with stroke having a decreased number of swings, as their subjective numbers validate. This was expected because increased co-contraction would
restrict the size of the swings of the limb, subsequently not allowing the limb to have enough momentum in order to produce as many swings as that of a healthy subject. It is possible this result was obtained because the computer software was able to record even the most minor swing, while the eye of the rater and judgment of the rater did not regard certain movements as swings anymore after the swing amplitude and velocity fell below a certain level.

When observing the individual muscle activation of each muscle tested, it is observed that the LQ and BF of patients with stroke fire with more force than healthy subjects, and the MQ and SM of these patients have decreased muscle activation when compared to the healthy subjects. It's possible that this is observed because generally in healthy subjects the medial muscles of the thigh, especially the MQ, tend to be weaker than that of the LQ, and in patients with stroke, this occurrence is further pronounced.

Latency of muscle activation of LQ, BF and SM were measured with reference to when the MQ activated for each trial. There was no significant difference between the control and experimental group here. This could be partially due to the small sample size and the low levels of spasticity most of our experimental subjects displayed.

Thus far the pendulum test’s reliability in evaluating spasticity in subjects with stroke is shown. Bohannon et al, Kim et al, and Kim, YW also show the reliability of the pendulum test in stroke, but their methods of performing the test differ from our this study's with the use of an NK table, Polhemus tracking system, and biomechanical model to determine reliability, respectively. The method used for performing the pendulum test in this study is one that can be more easily utilized in a clinical setting than the methods of the aforementioned researchers.
The pendulum test with proper relaxation may be a more reliable test for examining lower limb spasticity in patients with stroke than the Modified Ashworth Scale because it uses the weight of the patient’s limb and gravity as its main tools for performing the test. In this way, gravity is always a constant. In the MAS, there is no predetermined speed at which to move the limb that is being tested and scored. The absence of a universal or constant speed at which to perform this test makes the MAS even more subjective. The reliability of this measure decreases since it is difficult not only to reproduce similar speeds between raters, but also for the rater to keep the same speed across multiple trials, unless the rater adds a special measure to track the speed at which he or she is moving the limb.

**Patella Tendon Tap Test**

There are few studies which examine the patellar tendon tap test and its ability to examine spasticity in the stroke population, with the patellar tendon tap test being the focus. With hyperreflexia often being a related sign in spasticity according to Brown, it is unusual that such an easily executed test has not been more explored.\(^{15}\)

The initial amplitude of the limb movement in control subjects, especially their second and third swings are much larger than that of the experimental subjects. This is most likely due to the reduced or absent reciprocal Ia inhibition in participants with stroke causing the movement to be decreased. These first three swings of the limb are affected because of the stretch reflex elicited by the hammer hit, and then it appears these effects wear off with subsequent swings.

It can be seen that the velocity of the lower limb movement in participants with stroke is initially faster than that of the controls' and finishes with decreased speed. This is in accord with the hyperactive nature of reflexes in spasticity. When looking at the slope of the velocity of
participants with stroke, it can be observed that this line is not as smooth and continuous as that of the control participants. This is caused by reduced reciprocal inhibition.

It was observed that there was a difference in force used between control subjects and subjects with stroke and it was significantly different, but just barely so with a p value of .044. After performing several statistical tests on the averaged results, comparing velocity and amplitude with hammer force in subjects with stroke and then controls, and then comparing subjects with stroke, controls, and hammer force altogether, as well as running statistical tests on individual subjects comparing individual muscle activity and hammer force between different trials, it was seen that there was no correlation in all of these tests between the hammer force and the velocity and amplitude value. This means that the stretch reflex happens in an all or none fashion. Once the threshold force that causes the stretch reflex to occur is reached, the reflex will occur and play out as it may, regardless of if the threshold was just barely reached or if over-force was used with the hammer hit. These results show us that subjects with stroke have a lower threshold to elicit the stretch reflex. Lower threshold for subjects with spasticity with reflex hammer force is also seen in the Li-Qun Zhang et al’s study on spastic multiple sclerosis subjects. They also used a significantly lower force to elicit a reflex in the population they were studying.\textsuperscript{16}

When looking at offset latency, it is seen that participants with stroke had a delayed start for muscle activity when compared to control subjects. This is most likely due to co-contraction occurring when the stretch reflex is elicited.

When looking at peak latency, it is seen that the experimental subjects’ muscle activity has a faster onset than control subjects. This is what we expected since the alpha motor neuron is hyperactive in spasticity according to Bhakta.\textsuperscript{13} In Granata et al’s study, he found there was a
reduced mechanical delay in subjects with spastic cerebral palsy, similar to the results of this study.\textsuperscript{12}

It is quite clear that the hamstring and quadriceps muscles are being activated at practically the same time in subjects with stroke in both latency graphs, especially the lateral quadriceps along with the hamstrings, as Bhakta briefly discusses in his review.\textsuperscript{13} This is due to reduced reciprocal inhibition and increased reciprocal facilitation. The activity of the quadriceps and hamstrings in the raw data appears many of the times to be almost on top of each other in the subjects with stroke, whereas the control subjects have a clear distinction with the quadriceps activating first, then the hamstrings.

The individual amplitudes of all muscles tested were all much larger in our experimental subjects than those of the control subjects. This is due to increased reciprocal facilitation and increased tone caused by spasticity as discussed in Sheean et al’s study.\textsuperscript{17}

**Modified Ashworth Scale**

When performing the Modified Ashworth Scale, the test was conducted at slow speeds and fast speeds. The slow speed tests yielded subjective scores of 0, as was expected. The Modified Ashworth Scale when performed with increased velocity yielded different scores for varying levels of spasticity, as was also expected. However, in participants with stroke who appeared to have spasticity in both muscle groups (quadriceps and hamstrings) when the other two clinical tests performed the Modified Ashworth Scale revealed only one muscle group to be spastic. This may indicate that the Modified Ashworth Scale is not as reliable in detecting spasticity in subjects with stroke as the other two tests performed were. More data needs to be collected before this can be said with certainty, but the data is trending towards this conclusion. Blackburn
and N. Nakhostin-Ansari et al showed poor reliability of the Modified Ashworth Scale and Ashworth Scale in subjects with stroke, respectively, as well.\textsuperscript{5, 18}

At the moment, there appears to be no correlation between individual muscle responses and the different subjective values when performing the Modified Ashworth Scale in this study. This may show that although the Modified Ashworth Scale is sensitive enough to detect obvious spasticity, it is not sensitive enough to determine the degree of actual spasticity.

**Comparison Graphs**

Figure 4.1 compares data of the pendulum test to data from the MAS. It can be observed from this plot, that there are inconsistencies between the subjective score obtained from the MAS and what EMG data reveal in the pendulum test. For example, a subject receiving a subjective MAS score of 1 would be expected to have EMG data that yielded less hyperactivity of the muscle, whereas a subject receiving a subjective score of 3 would be expected to have increased EMG data for muscle activity. However, looking at Figure 4.1, it can be observed that subjects graded as having quadriceps spasticity with scores of 1 and 3 in the MAS have nearly identical EMG data.

Figure 4.2 shows similar inconsistencies between MAS and PTTT. A subject graded as having an MAS subjective score of 1 has increased muscle activation when compared to a subject with a 1+ score, and just the opposite would be expected.

Both of these figures suggest that the MAS is not as reliable in detecting spasticity in stroke as the pendulum test and PTTT are.
Figures 4.3 and 4.4 compare the PTTT to the pendulum test, and although no significant correlation was found between the two, a trend can be observed in both tests. With a larger sample size, it is possible these two graphs would show positive correlations.

Limitations

Limitations of this study include the sample size and the compliance of patients with stroke when performing tests such as the MAS. With a larger sample size, it is possible to obtain a more representative picture of the population we are studying and it will limit the influence of outliers or extreme observations in data analysis. A sufficiently large sample size would also allow for the production of results among variables that are significantly different. When conducting the MAS, the test was to be performed in sitting and in prone for all subjects; however, many experimental subjects opted not to lie prone for the test, so results from the prone position were not able to be analyzed.

Future Considerations

Future considerations for our study include having a larger sample size, comparing the involved limb to uninvolved limb, measuring resting knee flexion for pendulum and patellar tendon tap testing, and performing the pendulum test with subjects in a supine positions for increased relaxation (although this may not be as clinically feasible as sitting). Some important flaws with the MAS were highlighted during this study. This prompted the consideration for conducting a study to determine an objective speed to perform the Modified Ashworth scale. This would be beneficial in allowing for more accurate and repeatable results across different investigators.
Another consideration that arose was to conduct a study which times how long it takes to place electrodes and set up the machinery involved in this experiment in a clinical setting to determine the feasibility of performing these tests with objective measures in clinical practice. The results of this would be beneficial to physical therapy practice. These results can be compared to the amount of time it takes to conduct nerve conduction velocity testing and needle EMG tests as a means of showing that this would not only not take much time, but be worth the extra ten minutes or so to receive more accurate data, and therefore be able to give more precise treatments for varying degrees of spasticity.

Conclusion

By adding EMG, force sensors, and motion sensors to the pendulum test, patella tendon tap test, and Modified Ashworth Scale, these measures make these clinical evaluators more objective. These objective measures make these tests more reliable and help in determining which is the most reliable. All the tests performed are positively correlated for detecting spasticity. The pendulum test and the patella tendon tap test appear to be more reliable and sensitive in detecting the varying degrees of spasticity in subjects with stroke than the Modified Ashworth Scale. However, at the present time data is still being collected, so these results are not yet conclusive. Future studies will be conducted using this initial data as a starting point to attempt to establish a correlation between all three clinical evaluators of spasticity.
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