Instrumented Assessment of Abnormal Muscle Reaction

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Introduction

- Muscle spasticity affects millions of people worldwide.
- It is very difficult for health care professionals to manually assess the severity of the patient's muscle spasticity with accuracy, and thus makes it difficult to determine the appropriate treatment.
- To combat these difficulties, an automated method using two sensors was developed for the measurement of the spastic joint angle.
- Throughout the course of the experiment, it became apparent that the spasticity has a very clear signature in the position data.
- This signature allowed for the identification of the joint angle and velocity at the moment of spasticity.
- After further refinement, this device has the potential to make diagnosis and treatment of muscle spasticity easier and more accurate.

Current Assessment – Modified Tardieu Scale

- The Modified Tardieu Assessment involves manipulating the joint rapidly (the spasticity is often velocity dependent) until the therapist feels a sudden resistance, the R1 catch.
- The physical therapist then eases the joint past its "catching point" slowly.
- Oftentimes, the physical therapist is trying to determine the joint angle at which the muscle spasticity occurs.
- Since this joint angle is velocity dependent, it can vary depending on how fast the therapist manipulates the foot.
- The spastic joint angle is measured using a goniometer.
- This method is not very accurate in determining the joint angle, a value that physical therapists use to select and evaluate muscle spasticity treatments, and improvements are needed.
- This method is also not able to measure the spastic velocity, a value that potentially could make the assessment more consistent.

Figure 1: The Modified Tardieu Assessment. The therapist applies pressure to the sole of the foot rapidly until they feel the "catch." That joint angle is measured using the goniometer as shown in this image. The therapist then eases the foot past the "catch" until the foot is at its maximum dorsal flexion.
Photo credit:
https://www.youtube.com/watch?v=A0Cgoga4Rno

Materials - Sensors

- Polhemus PATRIOT ™ sensors
  - Able to track six degrees of freedom
  - Ideal for measuring position and orientation in real time
  - Chosen for their availability and performance

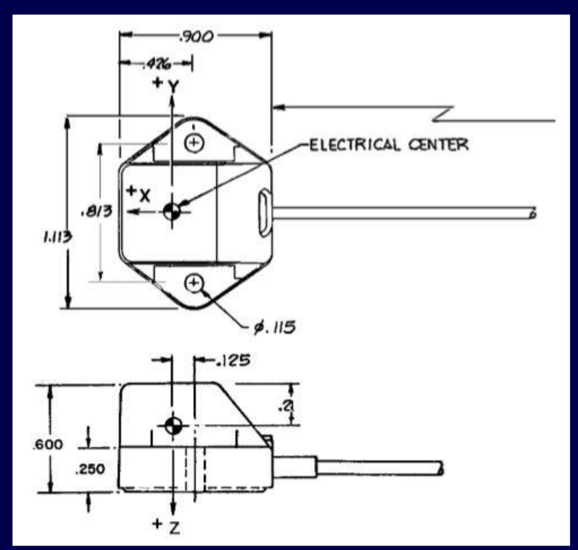

Figure 2: This image is the technical drawing provided by the Polhemus company. It demonstrates the dimensions and orientation of the sensor.
Photo credit:
https://polhemus.com/_assets/img/PATRIOT_brochure.pdf

Sensor Placement

- One sensor is securely attached to the frontal, proximal tibia using elastic Velcro.
- The second sensor is securely attached to the dorsal calcaneus using elastic Velcro.
- Before being attached to the calcaneus, the second sensor is used to locate the malleoli.
- The position of the both malleoli is recorded by briefly placing the second sensor on each malleoli and collecting data.
- Establishing the location of the malleoli allows for the flexion/extension axis of the talocrural joint to be established.

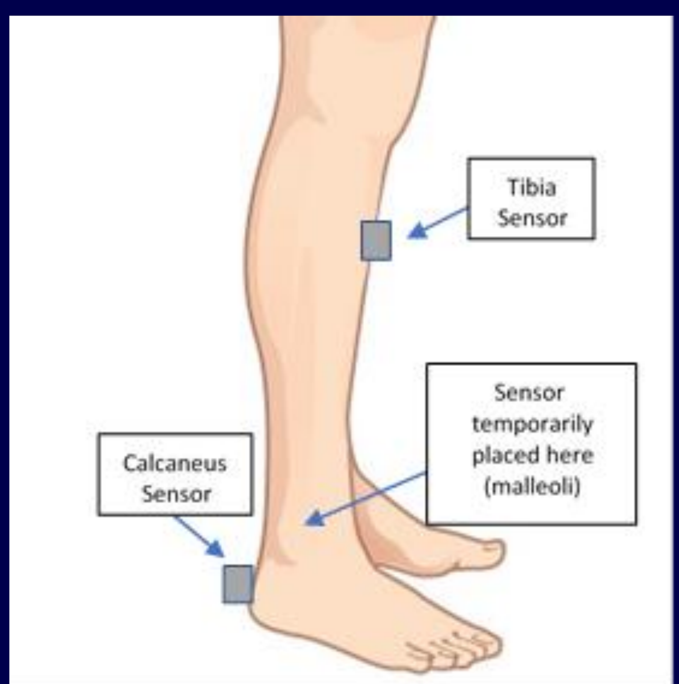

Figure 3: The placement of sensors. A sensor is attached to the tibia. The other sensor is briefly placed at both malleoli before being attached to the calcaneus.
Unedited image Case courtesy of Assoc Prof Craig Hacking, Radiopaedia.org, rID: 59080

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Using electromagnetic sensors, the joint angle and velocity of a spastic muscle can be recorded.

Results

- Figure 5: The velocity, shown as the orange line, begins steadily at zero before the assessment begins. It then raises rapidly as a force is quickly applied to the foot. The velocity reaches its peak value just before the spastic muscle catch and decelerates rapidly as the muscle resists any more dorsal motion. The second, smaller peak in velocity occurs as the physical therapist eases the foot past the spastic muscle catch. The velocity then returns to zero as the assessment ends.
- Figure 5: The joint angle, shown as the blue line, begins steadily at approximately -12 degrees. The negative angle indicates that the foot is in a slight plantarflexion position before the assessment begins. As the physical therapist applies a force to the foot, the ankle crosses over from plantarflexion to dorsiflexion and the angle becomes positive. The first peak on the joint angle graph gives the spastic joint angle. The maxima of this peak occurs when the velocity is zero because the foot has resisted any further motion. The second peak occurs as the physical therapist slowly eases the foot past that angle of muscle spasticity. The foot then slowly eases to full dorsiflexion as the assessment concludes.
- Assessing multiple trials, the average spastic joint angle for a single individual was 4.663 degrees (dorsiflexion). These values are similar to the estimated joint angle of 5 degrees (dorsiflexion) given by the physical therapist performing the assessment.
- The average spastic velocity for this subject was 226.8 degrees per second.
- There was a clear signature of the spastic joint angle and velocity in each of the trials performed on a single subject. This clear signature allowed for reliable identification of the joint angle and velocity within the code.

Discussion

- This method of determining spastic joint angle and velocity was able to reliably produce a joint angle similar to the one estimated by the physical therapist. It was also able to consistently measure a spastic joint velocity. Because of this, the two-sensor method of determining spastic joint angle and velocity seems a promising replacement for the conventional Modified Tardieu Assessment. However, further analysis and work must be completed before clinical and research implementation.
- Potential future work:
  - Determining the reliability of the method on different individuals
  - Analyzing the accuracy of the outputted data
  - Use in clinics and biomechanics research
  - Development of a rigid attachment system for the sensors
  - Adaptation for different spastic muscles other than the gastrocnemius
- This project still has a large amount of work necessary to ensure its accuracy and reliability. Further work on this project will test both of these qualities as well as expand applications. Currently, this project is able to identify the moment of muscle spasticity, output the spastic joint angle and velocity, and produce a graph of these values. This project shows progress and great potential for assessing abnormal muscle reaction using electromagnetic sensors.

Conclusion

Muscle spasticity affects millions of people worldwide and this device has the potential to aid in the assessment and treatment of these people. This design process has been able to successfully develop a device that can measure and output the joint angle and velocity at the moment of muscle spasticity. The device has demonstrated consistency with the estimated joint angle values given by a physical therapist. Further work should be continued on this project to assess the accuracy and reliability of the design as well as possible applications.

Methods – Assessment Procedure

1. Securely attach tibia (global) sensor using elastic Velcro
2. Place calcaneus (local) sensor on lateral malleoli, hold for 10 seconds and collect data
3. Place calcaneus (local) sensor on medial malleoli, hold for 10 seconds and collect data
4. Securely attach calcaneus (local) sensor using elastic Velcro
5. Place the foot in a neutral position and collect data for 10 seconds
6. Perform the Modified Tardieu Assessment while collecting data

- Four text files are generated during this process and are later analyzed by the code.
- The location of the malleoli is necessary to establish the ankle joint axis of flexion/extension.
- It is necessary that the sensors are placed at the tibia and calcaneus to get the relative motion during the Modified Tardieu Assessment.
- There is a telltale "signature" in the position (Figure 4) and joint angle data at the moment of spasticity. This signature allows the code calculate the spastic joint angle and velocity.

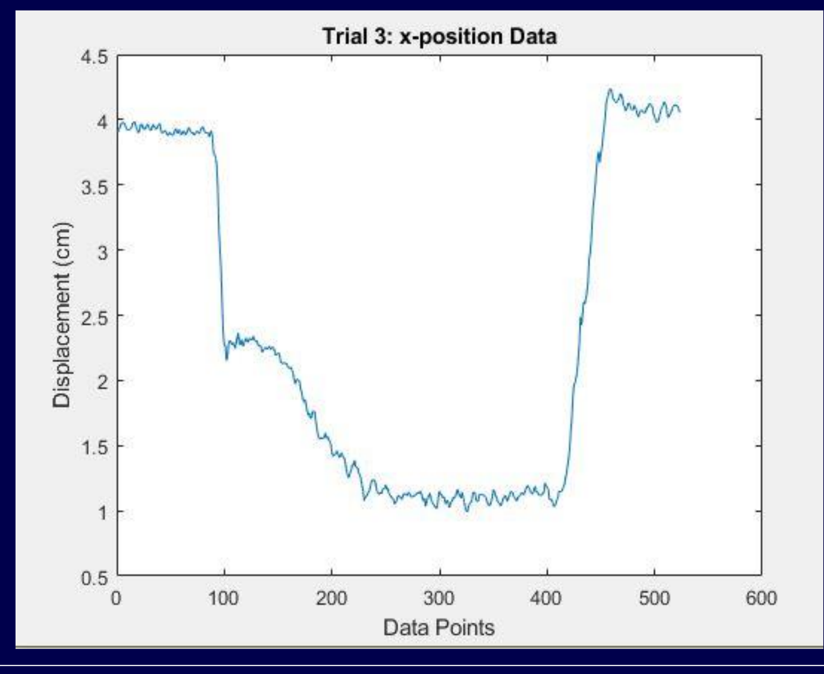


Figure 3: This image demonstrates how evident the R1 catch is in the collected data. The initial sudden drop is when the rapid force was applied to the sole. Where that linear line suddenly ends, is where the R1 catch occurs. The slope that follows, is when the therapist applies slower pressure to ease past that "catch."

Methods – MATLAB Code

- Four inputs: lateral malleoli text file, medial malleoli text file, neutral position text file, and Modified Tardieu Assessment text file
- Two outputs: joint angle and joint velocity

<u>Stage 1:</u>

- The code reads in the data from the two malleoli text files.
- It then finds the talocrural joint center, plantar/dorsiflexion axis, and a unit vector.

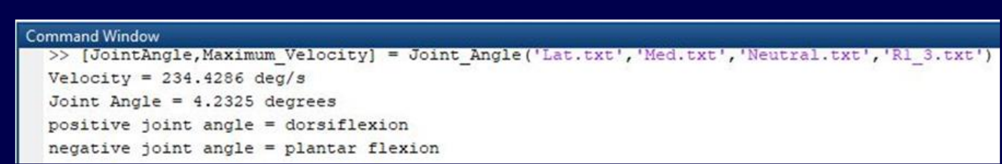
<u>Stage 2:</u>

- The code reads in the data from the neutral position text file.
- Next, it creates a rotation matrix that gives the relative angles of the calcaneus with respect to the tibia.
- Three vectors are then defined in the ankle location to create a coordinate system.
- This calcaneus coordinate system is coincident to the tibia coordinate system when the foot is in the neutral position, thus the relative rotation to the neutral position can be determined while the assessment is being performed.
- Two rotation matrices are then created and are assumed to behave as rigid bodies.
- The relative motion of these two rigid bodies can be calculated after the Modified Tardieu Assessment is performed.

<u>Stage 3:</u>

- The code reads in the data from the Modified Tardieu Assessment text file.
- Using the quaternions, another rotation matrix is created, similar to the first rotation matrix in stage two.
- Using this rotation matrix, the relative rotation of the calcaneus to the tibia can be calculated. Then, using this rotation, the angle about the ankle joint axis can be calculated. This gives the joint angle for every data point during the assessment.
- The velocity for every data point during the assessment is then calculated using the joint angle data and the sampling rate of the sensors.
- The joint angle and velocity are then plotted on the same graph (Figure 5) and scaled appropriately.
- The peak velocity and spastic joint angle are then calculated and outputted (Figure 6).

Figure 5: Joint Angle and Velocity of Modified Tardieu Assessment. The first orange peak demonstrates the spastic velocity and the first blue peak demonstrates the spastic joint angle.



```
Command Window
>> [JointAngle,Maximum_Velocity] = Joint_Angle('Lat.txt','Med.txt','Neutral.txt','R1_3.txt')
Velocity = 234.4286 deg/s
Joint Angle = 4.2325 degrees
positive joint angle = dorsiflexion
negative joint angle = plantar flexion
```

Figure 6: The output of the code. This output gives the physical therapist the units of the values as well as explains the connection between the joint angle sign and anatomical position.