Development of a clinician worn device for the evaluation of abnormal muscle tone

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Abstract— **Neurological disorders such as cerebral palsy commonly result in abnormal muscle hyperactivity that negatively effects functional use of the affected limbs. Individuals with cerebral palsy often present with a mix of spasticity and dystonia, and it can be difficult to distinguish between the effects of these types of abnormal tone. Different types of abnormal tone respond differently to treatments such as deep brain stimulation and baclofen. Conventional clinical evaluation techniques provide minimal information for distinguishing abnormal tone characteristics and changes from treatment. Devices that quantify abnormal tone characteristics can help distinguish between the effects of different types of abnormal muscle tone, and help to quantify treatment effects. This paper discusses the development and initial evaluation of MyoSense™, a clinician worn device for the quantification and differentiation of abnormal muscle tone. MyoSense evaluates the orientation, speed, and force during clinician manipulation of the affected limbs with a protocol that is similar to conventional practice for evaluating abnormal tone. Evaluation of the MyoSense device, using a mechanical apparatus to simulate abnormal muscle tone, showed good resolution of abnormal tone characteristics. Using a procedure directly modeled after conventional clinical evaluation of abnormal tone, MyoSense data showed good correlation with simulated profiles, 0.8 for spasticity and 0.93 for hypertonia. Evaluation of average change across different limb manipulation speeds, to mitigate acceleration and mechanical effects, resulted in MyoSense data correlations to simulated profiles of 0.99 for spasticity, spasticity with a catch, and dystonia. Overall these results show promise for future clinical evaluation of the MyoSense device.**

I. Introduction

Cerebral palsy effects 3.1 out of every 1,000 children in the United States and commonly results in abnormal muscle tone [1]. Abnormal muscle tone presents in many different forms for different types of neurological conditions. Individuals with cerebral palsy commonly present with velocity dependent resistance to passive movement (spasticity), and/or sustained or intermittent muscle contraction resulting in posturing or movement (dystonia). Mixed presentation of abnormal muscle tone types is common and it can be difficult to differentiate the effects of dystonia and spasticity [2].

While components of different types of abnormal muscle tone can appear similar during clinical evaluation, these conditions respond uniquely to treatments. For example, deep brain stimulation is effective at alleviating the effects of dystonia and improving function of the affected upper extremity [3] but has no established effect on spasticity. Additionally, while baclofen is generally effective for reducing lower extremity spasticity, the effect on dystonia is unclear and baclofen has resulted in increased dystonia for some individuals [4]. The ability to distinguish effects of dystonia and spasticity in individuals with cerebral palsy is important to avoid ineffective treatment [5].

Standardized methods for assessing abnormal muscle tone frequently rely on ordinal clinical rating scales that examine a certain characteristic of abnormal tone. For example clinical measures like the Modified Ashworth [6] for spasticity, and the Fahn Marsden Burke [7] for dystonia, ask the clinician to distinguish mild versus moderate effects using a 0 to 4 scale. These types of measurements only resolve very specific aspects of abnormal tone and are prone to subjective effects. Multiple review articles on the effects of treatments for spasticity and dystonia in individuals with cerebral palsy have noted significant limitations in the effectiveness of conventional clinical outcome measures [4] [8]. Additionally, research suggests that even in controlled simulated environments individuals find it extremely difficult to differentiate between mild to moderate abnormal muscle tone [9]. Devices that quantitatively assess abnormal tone could provide important insight in distinguishing characteristics of the affected limbs and assist with the evaluation of treatment effects.

While several robotic and patient worn devices have been developed to quantify abnormal muscle tone [10]–[12], these systems can not be easily implemented into standard clinical practice. While there are a few hand held devices for the evaluation of abnormal tone[13][14], they do not differentiate effects of manipulation speed or range of motion. This paper discusses the development and pilot testing of MyoSense™, a clinician worn instrumented device for the evaluation of abnormal muscle tone. MyoSense aims to provide a quantitative evaluation of abnormal tone characteristics with minimal interference with conventional clinical evaluation practices.

II. Device for Abnormal Tone Simulation

Abnormal tone can be highly variable with significant variation resulting from volitional muscle activation and muscle stretching. Because of this, it was important to provide initial validation of the MyoSense device using a simulated system. An abnormal muscle tone simulation system was created to model different types of abnormal muscle tone at the elbow. The system included a servo motor (Delco) with an encoder, gears, and a wood plank to simulate manipulation of the elbow (Fig.1). Motor torque was used to provide resistance

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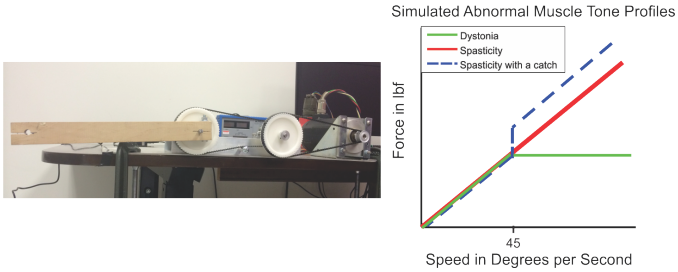

Fig. 1. Abnormal tone simulation device (left) and the speed dependent abnormal tone profiles that were modeled using the device (right).

to movement, which varied with position or speed based on the simulated condition. To reduce encoder noise, velocity data was filtered using a four point moving average with the system running at 100 Hz. This system had some limitations including slight lag in movement response due to slack in the belts and response time.

Four simulated abnormal tone modes of the elbow, which are common to individuals with cerebral palsy were created to evaluate MyoSense: hypertonia, spasticity, spasticity with a catch, and dystonia. The simulated speed affected abnormal tone profiles are shown in Fig 1. While the classification of abnormal muscle tone is not always straight forward, the following definitions of spasticity and dystonia were used to create simple abnormal tone simulated profiles based the literature [2][15]. Spasticity is the resistance to passive movement of the limb that increases with speed of passive actuation. Spasticity can present with a catch where resistance to movement increases with speed with a sudden sharp increase in resistance after a threshold is met. This is often associated with a release of resistance beyond this threshold, which was not included in our model. Dystonia is defined as involuntary sustained or intermittent muscle contraction. Our model of dystonia was based on rigid or posturing dystonia. This profile was modeled with increased manipulation speed resulting in increased resistance force with a constant resistance relative to increased speed beyond a speed threshold point. For simplicity, the threshold for both dystonia and spasticity with a catch was set to 45 degrees per second. While the definition of hypertonia is clinically variable, hypertonia is defined here as the resistance to slow movement, which changes with joint position [16]. This resistance is occasionally referred to the slow component of spasticity. However, that definition does not adequately account for the range of motion based effect. In clinical practice hypertonia is commonly observed as increased resistance as the elbow is moved into extension. The torque profile of this form of hypertonia is similar to the effects of contracture, muscle shortening, which also commonly occur in individuals with cerebral palsy. However, unlike contracture, hypertonia effects will decrease if the individual is able to relax their muscles.

III. MyoSense

MyoSense was developed as a clinician worn device for use during limb manipulation for the quantitative evaluation

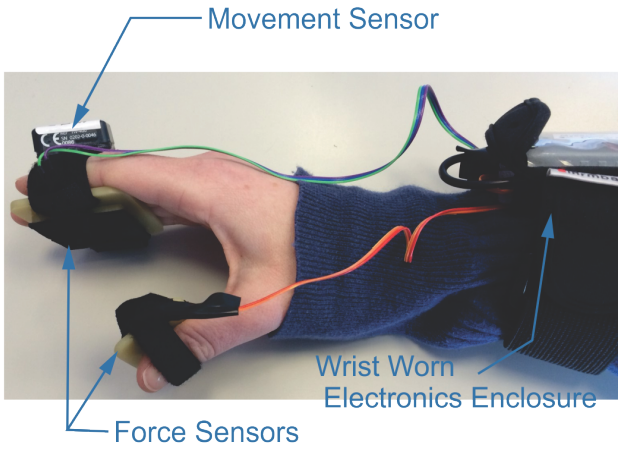

Fig. 2. The MyoSense device prototype with force and movement sensors.

of abnormal muscle tone (Fig.2). The device was designed with specific consideration of current clinical practice, so that only minor changes to standard procedures for evaluating tone would be required.

The MyoSense device included two force sensitive resistors (Flexiforce), which are held in opposition across the limb to cancel out the force applied when stabilizing but not moving the limb. A movement sensor, tri-axis accelerometer and tri-axis gyroscope (Great Lakes NeuroTechnologies), was used to measure angular velocity during the manipulation of the joint. The MyoSense device was designed to function wirelessly to increase wearability and general portability for clinical application. XBee (Digi) modules collected force data at 50 Hz and transmitted the signal wirelessly through radio frequency communication to a computer. The movement sensor recorded data at 64 Hz and streamed the data to the computer using Bluetooth communication. MyoSense output force, speed, and approximate orientation

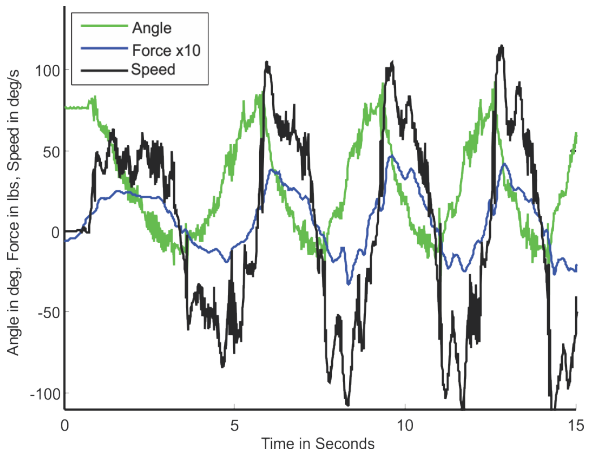

Fig. 3. The time based alignment of the force, speed, and approximate angle data collected with the Flexiforce sensors and movement sensor during cycling of the simulated spastic limb. The simulated limb started in the flexed position (approximately 90 degrees).

data as shown in Fig. 3. Sensor acceleration data due to gravity was used to calculate approximate angle of the limb during manipulation. While acceleration data is not ideal for orientation calculations due to movement effects, this value was only used while assessing hypertonia, which is evaluated at 5 degrees per second. At this speed movement effects on the orientation calculation are negligible. A computer interface provided real-time feedback about the speed that the limb was moved.

IV. Evaluation and Results

Direct comparison between speed, angle, and force characteristics during passive movement provides information about the abnormal tone profile and is most analogous to conventional clinical practice. A researcher cycled the simulated limb through flexion and extension in a 20 second trial for spasticity and a 70 second trial for hypertonia while wearing MyoSense. The data was separated into 10 point position (for hypertonia) or speed (for spasticity) bins. The average bin speed or position values and the average force values were examined. Fig. 4A displays the resulting profile for simulated hypertonia obtained from the MyoSense device with slow (5 deg/s) manipulation of the simulated limb. The figure shows the increase in force required to move the simulated limb as the limb moves into extension, toward zero degrees, as would be expected in a hypertonic elbow. The collected hypertonia data correlated well with the simulated profile (r = 0.93). The simulated spastic limb was moved at 90 deg/s as is done by clinicians during the Modified Ashworth examination of spasticity [6]. The direct comparison for spasticity is shown in Fig. 4B and the correlation to the simulated profile was 0.80. The figure shows the expected linear profile below 60 degrees per second but the trend is not consistent at higher speeds due to mechanical and response time limitations of the simulation device.

While direct comparisons can provide reasonable representation of the modeled spasticity and hypertonia profiles, this comparison method is highly effected by limb mechanics, changes in direction, and acceleration to reach goal speeds. For this reason, the speed dependent abnormal tone types were also analyzed across different average speed trials. The simulated limb was moved in separate 20 second trials at approximately 5, 25, 45, 65, and 85 degrees per second. The average speed and average force was calculated for each tracked speed. These profiles were then compared across different simulations. The calculated abnormal tone profiles showed good alignment in magnitude and slope until the simulated change at 45 degrees per second (Fig. 5). The slope of the high speed response (approximately 45 through 85 degrees per second) was compared to the low speed response slope (approximately 5 through 45 degrees per second). The data showed the expected general characteristics with the spasticity force response slope remaining relatively constant (increase of 25%) across the higher speeds, the spasticity with a catch response slope nearly doubling with an increase of 78%, and the dystonia response slope decreasing by 79% to almost constant resistance for the higher speeds.

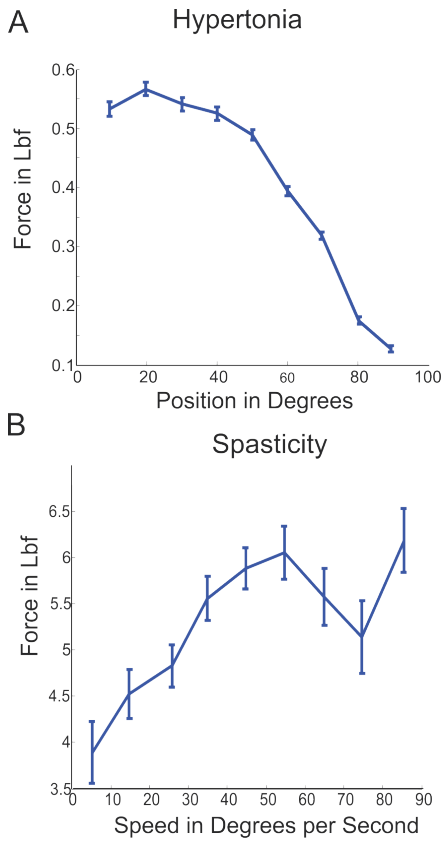

Fig. 4. Data collected by the MyoSense device during simulation of hypertonia (A) and spasticity (B) with standard error bars. The simulated hypertonic limb manipulation data showed expected increased resistance to movement with elbow extension and the simulated spastic limb data showed expected changes in force related to speed for speeds under 60 degrees per second.

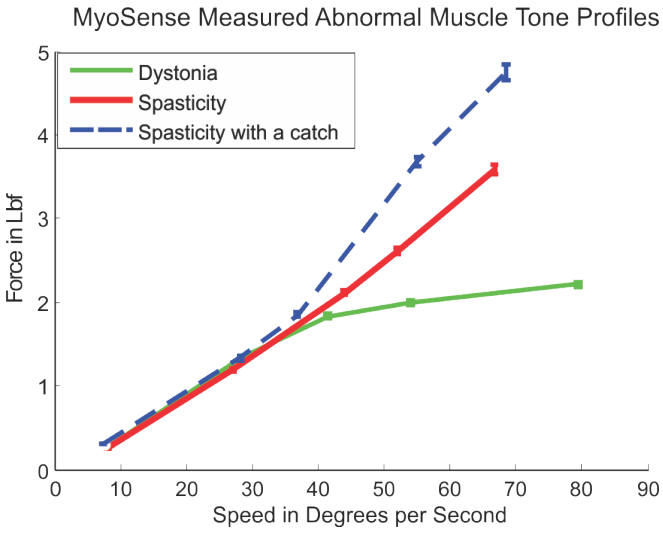

Fig. 5. Averaged MyoSense measured force and speed data during manipulation of different simulated abnormal muscle tone limb conditionals with standard error bars. The data showed the expected changes related to speed with good slope matching at low speeds and appropriate profile transitions around 45 degrees per second for dystonia and spasticity with a catch.

Table 1. Correlations between simulated and MyoSense measured data

	Simulated Spasticity	Simulated Spasticity with a Catch	Simulated Dystonia
MyoSense Spasticity	**0.998**	0.951	0.911
MyoSense Spasticity with a Catch	0.988	**0.991**	0.887
MyoSense Dystonia	0.918	0.802	**0.993**

The MyoSense collected data matched the corresponding simulated profiles well with correlations greater than 0.99 for all of the abnormal tone types (Table 1). Analysis comparing spasticity and dystonia data produced slightly lower correlations (between 0.8 and 0.92).

V. Conclusion

The results from the MyoSense evaluation showed the device's potential to quantitatively distinguish between different types and magnitude changes of abnormal muscle tone. Data obtained using MyoSense could be beneficial for the differentiation of effects of different types of abnormal muscle tone, and for the prescription and evaluation of abnormal tone treatments. Despite limitations in the abnormal tone simulator, MyoSense provided data with very high correlation to corresponding simulated profiles when evaluated across multiple speed trials and expected general changes in response with increased speed. Correlations between the MyoSense measured data and non-corresponding simulated tone profiles were marginally lower than correlations when comparing corresponding tone profiles (Table 1). This was likely due to the identical slow speed response of the different tone profiles and the small number of speeds tested. While correlations between spasticity and spasticity with a catch were particularly high, this was expected because these profiles follow the same general trend with increased speed. Additionally, differentiation between spasticity and spasticity with a catch profiles is not critical for patient care. Future work will include exploration of more robust methods to differentiate and quantify the relative effects of spasticity and dystonia.

A primary goal of MyoSense is to easily integrate into conventional clinical practice. Direct comparison between the speed and force data was evaluated because it has the best correlation to currently used clinical evaluations of abnormal tone. Although direct comparison did not provide the expected spasticity response at high speeds, it is possible that this simple method of evaluation will be effective for evaluation of abnormal muscle tone with only minimal effects due to limb acceleration during the movements.

These results suggest that further evaluation of the device's ability to distinguish characteristics of abnormal tone in individuals with dystonia and spasticity is merited. Future evaluation of the MyoSense device will examine the characteristics of abnormal tone in individuals with pure dystonia effects, and other individuals with pure spasticity effects. This clinical data will be used to evaluate MyoSense's ability to differentiate real world abnormal tone characteristics.

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