Evaluation of upper limb spasticity towards the development of a high fidelity part-task trainer

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Abstract

Upper limb spasticity is commonly seen in conditions of upper motor neuron pathology, of which includes traumatic brain injury, stroke, high cervical spinal cord injury and Cerebral Palsy. Trained physicians, physiotherapists and occupational therapists are needed for the rehabilitation of such patients. To obtain skills in addressing spasticity, current practice in training of students utilizes patients as primary learning subjects. Novices without the required skills put the patient safety at stake. Further, physicians and therapists evaluate spasticity using the Tardieu, Ashworth, and Modified Ashworth Scale which can vary dependent on experience. Variability in rater scores suggest that training can be improved. To tackle this issue, an upper limb part-task trainer that is capable of consistently emulating spasticity symptoms is proposed for pre-clinical training of physicians, therapists and medical students. In order to obtain clinical data for the emulation of upper limb spasticity symptoms, a non-invasive evaluation procedure has been designed deploying a goniometer and a manual muscle tester. The goniometer measures the angle of elbow joint of the patient while the manual muscle tester measures the force applied by the rehabilitation physician on the patient’s forearm. The elbow joint angle and its resistance force are recorded in real time via a data acquisition interface and NI LabVIEW software. The evaluation procedure was carried out by a rehabilitation physician during a routine rehabilitation session to the patients with symptoms of upper limb spasticity.

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1. Introduction

Spasticity is one of the upper motor neuron syndrome (UMNS) that interferes with basic motor tasks which is required to accomplish activities of daily living. The definition of spasticity was put forth by Lance (1980): “spasticity is a motor disorder characterized by a velocity dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyper-excitability of the stretch reflexes, as one component of the upper motor neuron syndrome”. When passive force is applied to the muscle, stretching the muscle inappropriately increase muscle tension and give resistance to passive motion. Cerebral palsy and stroke are two common conditions that exhibit spasticity. According to National Stroke Association of Malaysia (NASAM), stroke is the third largest cause of death in Malaysia. Cerebral palsy on the other hand is the most common congenital disorder of childhood.

A few methods have been used for spasticity assessment as discussed in [1] including its reliability. Most frequent method used to evaluate the severity of spasticity symptoms is the Ashworth Scale and the Modified Ashworth Scale (MAS) [2]. These methods are simple, and require no instrumentation. However, the reliability of these methods has been discussed in some studies [1][3][4]. The score variability is partly due to the differing interpretation of the descriptions of grades in MAS, for example, terms such as ‘slight increase’, ‘considerable increase’ and ‘passive movement difficulties’. It is also unclear on how to clarify the speed required during the assessment for fast flexion movement. Furthermore, it is reported that there are no standardization in training or written guidelines for determining MAS [5].

It is important for therapists and medical students to have adequate training before using the MAS procedure and study the range of speed necessary [1]. In order to provide adequate training using the MAS procedure, a quantitative results comparison with the MAS level is important as a fundamental preparation. Spastic limbs demonstrate abnormal resistance to imposed joint movement. This resistance is augmented by increasing the angle of deflection and the rate at which the limb is moved. Torque is proportional to the amount of muscle force elicited by moving that limb through a specified angle. Torque as a measure of resistance to imposed movement is the result not only of the reflex response but also of the passive properties of the tissues [6]. Resistance torque offers a fair quantitative correlate of the Modified Ashworth Scale (MAS) in assessing spasticity [7].

1.1. Part-task trainer based on simulated patient data

A prototype of upper limb disorder part-task trainer has been developed [8]. The aim is to provide the physicians and therapists with adequate training sessions before they carry out their clinical spasticity assessment. Besides increasing the frequency of training for physicians and therapist trainees, such an approach will increase the reliability of MAS assessment. Within the part-task trainer, a Magneto-Rheological (MR) brake (Lord RD-2087-01) acts as the main passive actuator used to produce the resistance for a constant stiffness and supported by a DC servo motor (SANYO L404-011 NE) to assist the time delay of the fluid particle settling rate of Magneto-Rheological fluid depending on the severity of the symptom. The mechanism of the upper limb disorder part-task trainer shown in Fig. 1(a) is based on the spasticity model consists of human upper limb anatomy and pronation/supination movement and flexion/extension of elbow joint.

The control scheme of the upper limb disorder part-task trainer is designed based on the simulated patient data shown in Fig. 1 (b). The data was obtained from an assessment involving two therapists, one of them as a simulated patient emulating the spasticity symptoms. The pre-catch and catch phenomenon were measured using a load cell muscle tester (μTas MT-1 Anima Corp.) with a range of 0-100 kg, and the elbow joint angle was analyzed using FrameDIAS which is a marker motion capture system. The device is designed to provide resistance to the passive movement given by the therapist during an extension of the forearm of the simulated patient. The MR brake continuously produces stiffness depending on the angle measured by encoder, and the process is supported by a DC motor.
1. Clinical data collection for a high fidelity part-task trainer

A series of quantitative assessments on upper limb spasticity has been conducted by an experienced rehabilitation physician supported by a team of engineers. The force induced by the rehabilitation physician and the elbow joint angle of the patient during a passive stretch motion of the forearm was measured. The Tardieu scale, spasticity angle and the Modified Ashworth Scale were used for the evaluation of severity level. The measurement outcome includes angular position and muscle resistance force caused by patient’s muscle activation. Such clinical database of upper limb spasticity symptoms is novel because it is the first database specific to Malaysian patients which can be useful for studies on kinesiology. Further, the database can be applied for modeling the envisaged behavior of the upper limb disorder part-task trainer described in Section 1.1 including the system states, the state transitions as well as the events that trigger a state transition.

2. Method

The ethics approval for this research has been granted by the Medical Research and Ethics Committee of the Ministry of Health Malaysia [Ref. NMRR-13-1384-18681 (IIR)] and the Research Ethics Committee of Universiti Teknologi MARA [Ref. 600-RMI (5/1/6)]. The stroke patients were screened by a rehabilitation physician before the evaluation of spasticity using the MAS and Tardieu scale. All subjects involved signed a consent form prior to the clinical measurement. The clinical measurement was conducted at the Clinical Training Center at the Faculty of Medicine of Universiti Teknologi MARA in Malaysia.

2.1. Measurement set-up

The rehabilitation physician is supported by a team of engineers during the clinical measurement, especially to handle the set-up and operation of a digital goniometer and a manual muscle tester. Fig. 2 illustrates the active structure [9] of the clinical measurement set-up. Fig. 3 shows the position of the rehabilitation physician and the subject during the clinical measurement.

A goniometer (GNM-BTA from Vernier) was used to measure the range of motion of the elbow joint. It is a Vernier product with an angle sensor attached to a metal stationary arm. It comes with a set of Velcro straps used to fix the sensor to patients arm for measurements of the elbow joint movement. On the other hand, a manual muscle tester (Mobie MT-100W) was used to measure the force given by the rehabilitation physician on the forearm of the subjects during a passive stretch motion. It is a product of SakaiMed and has a push sensor structure. It was placed at the rehabilitation physician’s palm.
Both the goniometer and the manual muscle tester are connected to a Vernier SensorDAQ for data acquisition using LabVIEW software. The goniometer was connected through digital hub while manual muscle tester was connected through Vernier analog sensor using British Telecom Analog Connector.

![Diagram](image)

**Fig. 2.** Measurement device setup connection for the clinical data collection.

![Images](image)

**Fig. 3.** (a) Goniometer and manual muscle tester; (b) Patient arm attached with measurement devices and position of rehabilitation physician-patient; (c) Passive stretch motion conducted by rehabilitation physician.
2.2. Experimental protocol

The assessment procedure is non-invasive in nature. It is similar with the procedure of a therapist or physician during a rehabilitation session/assessment to the patient suffering upper limb spasticity. The assessment procedure is elucidated in Fig. 4. The evaluation procedure involves a fast motion and a slow motion assessment. During the fast motion assessment, the rehabilitation physician stretches the forearm of the patient as fast as he or she could manage, and a catch is expected to take place. In the slow motion assessment, the rehabilitation physician stretches the forearm of the patient as slow as he or she could manage until the fully stretched position.

![Flowchart of experimental protocol](image)

**Slow Motion Assessment**: The forearm of the patient is extend as slow as the rehabilitation physician could cope until the fully extend position. Determine the angle $\theta_2$ and the torque $\tau_2$ at the fully stretched position from the goniometer and the muscle strength meter.

**Fast Motion Assessment**: The forearm of the patient is extending as fast as the rehabilitation physician could manage until fully extension. A catch is expected to occur. Determine the angle $\theta_1$ and the torque $\tau_1$ when catch happens from the goniometer and the muscle strength meter.

**Severity Evaluation**: The difference in terms of the angular position detected during the fast and slow motion assessment can be used to determine the level of severity. Both the Tardieu Scale (Table 1) and the Modified Ashworth Scale (Table 2) will be applied.
Table 1. Description of Tardieu Scale.

| Scale | Description                                                                 |
|-------|-----------------------------------------------------------------------------|
| 0     | No resistance throughout passive movement                                  |
| 1     | Slight resistance throughout, with no clear catch at a precise angle        |
| 2     | Clear catch at a precise angle, followed by release                        |
| 3     | Fatigable clonus (< 10secs) occurring at a precise angle                    |
| 4     | Not fatigable clonus (> 10secs) occurring at a precise angle                |
| 5     | Joint immobile                                                              |

Table 2. Description of Modified Ashworth Scale

| Scale | Description                                                                 |
|-------|-----------------------------------------------------------------------------|
| 0     | No increase in muscle tone                                                  |
| 1     | Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion (ROM) when the affected part(s) is moved in flexion or extension |
| 1+    | Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM |
| 2     | More marked increase in muscle tone through most of the ROM, but affected part(s) easily moved |
| 3     | Considerable increase in muscle tone, passive movement difficult            |
| 4     | Affected part(s) rigid in flexion and extension                             |

2.3. Sample size and inclusion criteria

In order to classify the severity level of patients’ spasticity, the sample size required is estimated at 97 subjects as shows in Fig. 5. The calculation was done using the PS-power and sample size calculation software.

Fig. 5. Sample size calculation.
The inclusion criteria for the screening of patients include the following; 1) Adult above 18 years old, 2) Diagnosis of central nerve system disorders, 3) Consent of patient, and 4) Ability to understand and follow commands. It involves interviewing and examining the subject and reviewing records to obtain an accurate description of current symptoms, functional abilities, and medical history.

3. Measurement results

Table 3 describes the diagnostic data of the study sample. All of the patient's symptom was caused by stroke. Types of stroke was classified as either ischaemic, hemorrhagic or unspecified. Mechanism of cell injury may be caused by a deficit of oxygen and nutrients in the brain cells or toxicity due to rupture or a blockage of a blood vessel.

Table 3. Diagnostic data for study participants.

| ID | Gender | Cause                  | Side | MAS Score |
|----|--------|------------------------|------|-----------|
| 1  | F      | Ischaemic              | L    | 1         |
| 2  | M      | Stroke Unspecified     | L    | 2         |
| 3  | M      | Stroke Unspecified     | L    | 1+        |
| 4  | M      | Haemorrhagic Stroke    | R    | 0         |
| 5  | M      | Ischaemic Stroke       | R    | 1+        |
| 6  | F      | Ischaemic Stroke       | L    | 1+        |
| 7  | M      | Ischaemic Stroke       | L    | 0         |

The assessments were conducted in real time. The collected data were analyzed according to its motion speed and compared with the Modified Ashworth Scale as described in Table 2. The collected data includes the angle of elbow motion and the force applied by the rehabilitation physician to the patients.

Fig. 6 shows the results of ischaemic stroke patient with moderate tone of MAS score (1+) of patient 5. During fast motion stretch, a catch occurred at angle 136 degrees where the peak of the force is shown at 64 [N]. The catch angle occurred in between 90 - 180 degrees thus showing that the patient is under level 1+ of Modified Ashworth Scale. According to the rehabilitation physician, the patient showed minimal resistance throughout the remainder of the range of motion (ROM), however the rehabilitation physician started releasing the manual muscle tester resulted in force decrement after the catch. The maximum angle of motion is at 152 degrees when the forearm was stretched in slow motion. The slow motion stretch did not show any sudden increase in the force given by the rehabilitation physician and the elbow angle shows an even increment contrasting the fast motion stretch. The spasticity angle is measured by the difference between fully stretched angle and the position angle when the catch occurred.

Fig. 7 shows the result of patient 6 with Modified Ashworth Scale level 1+ following the same characteristics with patient 5. There was a sudden increase in muscle tone showing the catch position occurred at 152 degrees with a fully stretched angle at 165 degrees. Minimal resistance was left throughout the remainder of the ROM until the rehabilitation physician released the manual muscle tester.
Fig. 6. Results for patient 5 with moderate tone MAS +1 during slow extension and fast extension.

Fig. 7. Results for patient 6 with moderate tone MAS +1 during slow extension and fast extension.
4. Programming approach

A programming approach is proposed for the emulation of the different levels of spasticity. The system starts with the part-task trainer being in a full flex position at 140 degrees of the elbow joint angle. Fig. 8 shows a flowchart for the spasticity emulation program. The elbow joint angle is divided into three phases, from full flexion to full extension positions. In the range of 140-101 degrees of the elbow joint angle, the system provides maximum resistance using only the MR brake. This range of the elbow joint angle shows the muscle tone phenomenon. After entering the range of 100-41 degrees of the elbow joint angle, the resistance from the MR brake and DC motor is reduced depending on each angle decrement. Finally when the elbow joint angle is almost in the full extension position, a constant resistance is inserted by the MR brake and the DC motor. In order to repeat the training, the part-task trainer needs to be returned to the fully flexed position.

![Flowchart for emulation of spasticity.](image)
5. Conclusion

A novel approach for clinical measurement of upper limb spasticity has been developed. The approach is supported by a digital measurement and data acquisition system. Using such an approach, clinical measurement has been conducted on seven post-stroke subjects. The collected clinical data are preliminary findings and more data will be acquired to be used for the development of a spasticity upper limb part-task trainer. Such finding contributes towards understanding the kinesiology of a spastic upper limb as well as tackling the issue of the variability in rater scores for upper limb spasticity. These outcomes will lead to improving the quality of student training and thus the quality of patients care during rehabilitation sessions.

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