QUANTIFICATION OF SPASTICITY USING REPETITIVE MOVEMENTS

Hermens H.J., Migchelbrink J.H., Rutten W.L.C.* and Postema K.

Rehabilitation Centre Het Roessingh
* Twente University, dept. of Biomedical Engineering
Enschede, THE NETHERLANDS

Keywords: spasticity, EMG, repetitive movements

INTRODUCTION

Generally, deviations in motor function of central origin, are characterized by paresis and spasticity.

The degree of paresis may be quantified in several ways. The most common way in clinical examination is to quantify the muscle force by means of the 6 grade MRC-scale. More quantitative methods involve the measurement of muscle force or measurement of the EMG activity by means of surface EMG [1].

Spasticity however is much more difficult to quantify. Partly this is due to lack of understanding of the mechanisms that cause spasticity. On the other hand, quantification is made difficult by the different ways spasticity may express itself (e.g. rigidity, clonus, claspknife phenomenon). The most simple and most investigated symptom is probably the resistance of a spastic muscle against passive stretch. In rehabilitation the Ashworth-scale is often used to categorize this resistance into five grades. However disadvantages of the Asworth-scale are its non-linearity and its relative insensitivity to small changes in spasticity. These properties make this scale hardly suited for use in follow up investigations, which is an important item in rehabilitation.

With the "pendulum test" [2] the damping of the lower leg is investigated during free passive swing. An advantage of this method is the relatively simple equipment needed, which makes it suitable for clinical use. A disadvantage is that the passive mechanical properties of the knee joint and the muscle/tendon system are also measured, which will influence the result.

Also research has made use of repetitive passive [3] or active [4] movements of the knee joint. With this latter kind of research not only increased stretch activity is considered, but also the central control of the movement. It may be expected that this approach will contribute more to the development of a clinical tool because it is more closely related to activities of daily life. On the other hand it may be expected that this kind of research is more complex.

Postema [5] (together with Prevo) investigated the EMG patterns of knee flexor and extensor muscles and the knee angle, during rapid repetitive movements. Postema paid special attention to the analysis of the goniometer signal, but from his work it appeared that information could also be present in the EMG patterns itself. Therefore we started to investigate this in a more systematic way. This paper deals with the first results obtained in a pilot study.

METHODS

Measuring set-up

The subject is seated in a special chair with the lower legs hanging free. Surface electrodes with built in pre-amplifiers (amplification: 100 times; bandwidth: 8 Hz-15 kHz) are placed on the Rectus femoris and Semitendinosus muscles according to fixed protocols. The arms of a potentiometer are attached to the upper and lower leg in order to measure the knee angle.

The EMG signals are amplified and filtered (Bandwidth: 8-320 Hz; slopes 12 dB/octave). At the input of a DEC LSI-11-03 mini computer, the two EMG signals and the goniometer signal are sampled (sample rate 1 kHz) during 6 seconds and digitized with a 12 bit AD-converter. The recordings are started by means of a footswitch. The signals are stored on floppy disc together with administrative data.

Measuring protocols

With each investigation first EMG recordings are made at rest and during maximal isometric contraction of the Rectus femoris and Semitendinosus muscles. Afterwards these recordings may serve to normalize the recordings obtained during the passive and active movements.

The activity of the muscles during passive movements is recorded in two ways. First the pendulum test [2] is carried out. This means that the lower leg is brought up to a horizontal position after which it is released. The recordings are started by means of a footswitch just before the leg is released.

During the second test the lower leg of the subject is moved by the investigator alternatingly, from 90° degrees flexion to full extension. This is done in a regular way and at different frequencies of movement (range 0.4-1.2 Hz), which are kept constant by using a metronome. The recordings are started as soon as the movement has reached a steady state.

The third test comprises the active movements. The subject is asked to move his lower leg in a steady way, between 90° flexion and full extension of the knee. Recordings are made at different frequencies of movement (range 0.3-2.6 Hz). First the subject is asked to move the lower leg at his most comfortable frequency of movement (Fc). Consecutive recordings are made at lower and higher frequencies· the last two recordings at maximal frequency. Special attention is paid to ensure that the range of motion stays the same for all registrations.

It was choosen not to supply any feedback of the frequency to the subjects because in case of central disorders additional deviations control may be expected (especially with hemiplegic subjects). Here also the recordings are started when the movement has reached a steady state.

Signal analysis

Interactive computer programs were developed to analyse the signals. It was decided to pay attention to two aspects of the signals; the timing of the EMG-bursts with respect to the goniometer signal and the amount of EMG, expressed as the standard deviation of the signal. In order to eliminate movements artefacts in the EMG signals the sampled signals are filtered with a digital high pass filter. This filter has been realised by applying a rectangular moving average window (width: 31 points) twice to the original data and subtract the resulting data for each point from the original data. Important advantages of this type of filter are the absence of phase distortion and the relatively short computer time consumption.

The next step of the program is to calculate the number of local maxima and minima of the goniometer data in order to determine the frequency of the movement. Then the variance and the standard deviation of the EMG signals are determined over an integer number of movement cycles.

The next step is to determine the timing of the EMG bursts. First the absolute values of all EMG samples are calculated. Then a rectangular moving average window (width: 31 points) is used to create a low pass filtering with zero phase shift. During this step also the minimal and maximal values are determined. From these values a threshold value is calculated and used to determine the start and stop of each burst. In order to determine whether a burst will count as a real burst a number of additional conditions are added. These are:

- a burst should last longer then 30 mSec.
- the amplitude of the smoothed EMG within a burst should exceed a specific treshold level.

The timing of the EMG bursts is always related to the phase of the movement, i.e. from 0 to 2π in which 0π equals maximal flexion and π equals maximal extension.

The results of the calculations are stored on floppy disc. Graphic output may be made of each step during the calculation of the timing and of the final results.

Subjects

The EMG and goniometer patterns were determined for 10 normal subjects (age between 22 and 32 years; 8 male, 2 female).

A pilot study was performed for 8 hemiplegic subjects. The most important data are shown in table I. The subjects were selected on their ability to perform knee stretching at grade 3 (MRC-scale) and absence of contractures.

All subjects were informed on the purpose of this study and they gave their informed consent.

Table I. Data of the hemiplegic subjects.

Subject code	Male/ female	Age	Time aft. stroke	Left/right sided hemipl.	Ambulation status
1008	f	69	3 m.	r	walks
1009	f	53	12 m.	l	wheelchair
1013	m	39	15 y.	l	walks
1016	f	83	3 m.	l	walks
1007	m	47	10 m.	r	wheelchair
1012	m	62	26 m.	l	walks
1014	m	57	10 m.	r	wheelchair,
1015	f	74	3 m.	l	wheelchair

RESULTS

Normal subjects

During the passive tests none of the normal subjects showed any significant (st.dev.>10 uV) burst activity in the EMG recordings. From the goniometer recordings of the pendulum test it was calculated that the mean value of the frequency of movement was 0.95 Hz (st.dev. 0.04).

The amount of EMG activity as function of the frequency of movement during the active test is shown in figure 1.

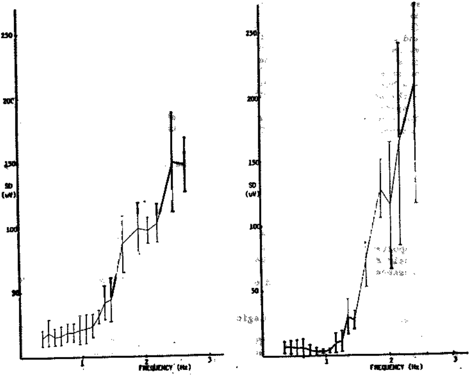

Figure 1. The standard deviation of the Rectus femoris (A) and the Semitendinosus (B) as function of the velocity of movement (10 normal subjects).

As shown in figure 1A the activity of the Rectus femoris shows little dependence on the frequency of movement until the frequency that coincides with the most comfortable frequency (Fc) of movement (mean value 0.88 Hz; st.dev. 0.08). The activity of the Semitendinosus, as shown in figure 1B, shows a minimum value at this frequency. At frequencies higher then Fc the activity, needed to perform the movement, strongly increases.

Figure 2 shows the timing of the start and end of the EMG bursts, with respect to the goniometer signal as a function of the frequency of movement.
From figure 2A it can be seen that a rather distinct phase shift occurs at Fc. During slow movements, at frequencies less then Fc, the Rectus femoris is active during extension but also during a large part of the flexion. This is probably done to avoid a quick return of the lower leg due to the gravity. With faster movements the Rectus femoris is activated before the maximal flexion is reached and is stopped before full extension.

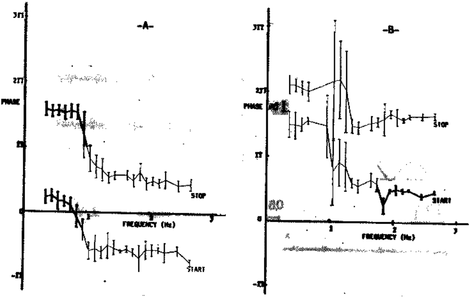

Figure 2. The timing of EMG bursts of the Rectus femoris (A) and the Semitendinosus (B) related to the phase of the movement as function of the velocity of movement (10 normal subjects).

Figure 2B, the phase shift of the Semitendinosus shows a similar course as function of the frequency of movement; with frequencies of movement less then Fc, the semitendinosus is activated between approximately halfway flexion and maximal flexion. With frequencies higher then Fc, the Semitendinosus is activated during a longer time; approximately between halfway extension upto halfway flexion.
Comparing the regions of activity of both muscles with frequencies larger then Fc, it is important to notice that there is some overlap in activity during flexion, when the Semitendinosus is still activated and the Rectus fem. gets activated. In the opposite case there is hardly any overlapping activity. Probably this is caused by the asymmetry of the movement with respect to the direction of gravity.

Hemiplegic subjects

Conform to the measuring protocol, the results will be presented in three different parts.

1. The pendulum test

Considering the EMG patterns we may distinguish 4 categories.

- No activity (st.dev.< 10 uV) in both muscles (3 subjects. 1009,1013,1016).
- **II.** Continuous activity in one **or both muscles (2 subjects: 1007, 1008).**
- **III.Reflex activity in the Rectus femoris (2 subjects:1012,1015).**
- **IV. Reflex activity in both muscles (1 subject: 1014).**

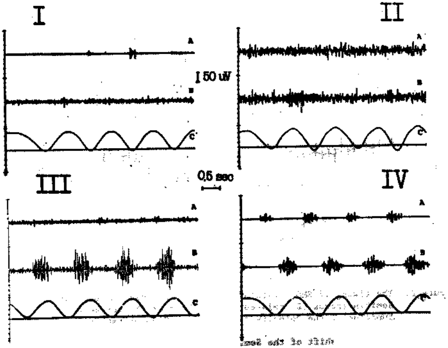

Figure 3. Typical examples of the four different categories found with the pendulum test. Shown are the EMG signals of Rectus femoris (A), Semitendinosus (B) and knee angle (C).

Figure 3 shows typical recordings of the four different categories. Regarding the movement, in terms of the goniometer signal, the following remarks can be made:

In category I and II the goniometer signal shows a sinusoidal course, whereas in category III and IV often deviations occur.

The time needed to come to a stable position tends to decrease with successive category numbers; ranging from longer than the recording **time (I) upto less than half the recording time (IV).**

- The decay of the goniometer signal tends to be larger with successive category numbers.
- The frequency of movement shows higher values in the higher categories. Especially a difference seems to exist between the first two (Fp< 0.95) and the last two categories (Fp> 1 Hz).

2. Passive movements

Considering the EMG patterns, recorded at frequencies of movement between 0.5 and 1 Hz, we may distinguish four categories:

I. No activity (st.dev.< 10 uV) in both muscles (1 subject: 1016).
II. Continuous activity in one or two muscles (1 subject: 1008).
III. Reflex activity in one muscle (2 subjects: 1009, 1013).
IV. Reflex activity in both muscles (4 subjects: 1007, 1012, 1014, 1015)

Typical recordings of each category are shown in figure 4.

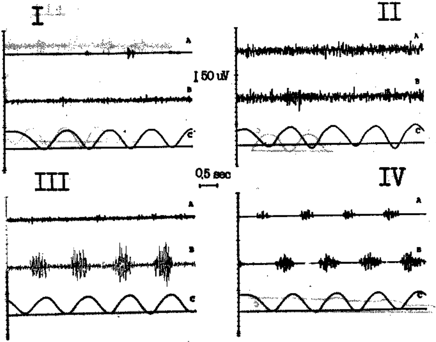

Figure 4. Typical examples of the four different categories found with the passive test. Shown are the EMG signals of Rectus femoris (A), Semitendinosus (B) and knee angle (C).

Note that only one subject showed no activity during passive movement.
Generally we did not find a correlation between the frequency of movement and the timing of the EMG bursts. The bursts in the Semitendinosus generally start shortly after the start of extension and

last upto full extension or slightly longer. The bursts in the Rectus femoris generally start later, approximately halfway the flexion, and they last upto the turning point of the movement or slightly longer.

Active movements

Considering the EMG signals we may distinguish four categories:

I. Only burst activity (no subjects).

II. Burst activity in the Rectus femoris and continuous activity in the Semitendinosus (2 subjects: 1008, 1016).

III. (Altered) burst activity in the Rectus femoris and activity during extension in the Semitendinosus (2 subjects: 1009, 1013).

IV. No burst activity in the Rectus femoris (4 subjects: 1007, 1012, 1014, 1015).

Typical recordings of the three categories are shown in figure 5.

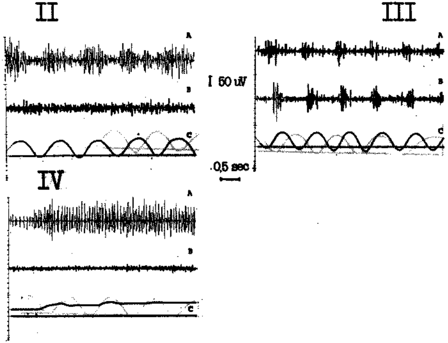

Figure 5. Typical examples of the three different categories found with the active test. Shown are the EMG signals of Rectus femoris (A), Semitendinosus (B) and knee angle (C).

In category II both subjects managed to perform a good sinusoidal movement, despite the continuous antagonistic activity. In category III one subject was able to perform a good sinusoidal movement while the the other subject could only perform a disturbed sinusoidal movement at a low frequency. In category IV hardly any movement (<10 degrees) could be observed with all subjects.

DISCUSSION

In the measuring protocol three different tests were included. The first two measure the response of the neuromuscular system to passive movements of the lower leg. The third test also measures aspects of the neuromuscular system to perform a relatively simple task. The finding that only half of the hemiplegic subjects were able to perform this task indicates a serious loss of motor control with these subjects. Additionally it may be remarked that all the hemiplegic subjects were able to reach grade 3 (MRC-scale) during extension, which points to differences between this task and the task to perform a repetitive movement.
Generally it is found that the timing of the stretch reflex is both dependent on the length of the muscle and the velocity of the lengthening. Therefore one expects an advanced phase shift with higher frequencies of movement. However the results of the second (passive movement) test generally do not show a relation between the frequency of movement and the timing of the EMG bursts. Our results indicate that the reflex activity is probably started by exceeding a treshold length of the muscle. The fact that the reflex activity generally stops at the turn of the movement indicates that this stop is probably caused by a velocity dependent reflex mechanism.
In the hemiplegic subjects that were able to perform the third test (active movement) no distinct deviations from the normal timing were found; except for the presence of reflex activity. Yet it was remarkable that within this group, no hemiplegic subject was able to perform the test at frequencies higher than Fc. This could indicate a loss of the ability to change the timing, needed to achieve faster frequencies of movement.

The results of the pilot study indicate that surface EMG provides an excellent non-invasive tool to investigate aspects of neuromuscular control. The amplitudes and the timing of the EMG signals are directly related to the neuromuscular control, whereas with mechanical measurements this is investigated in a rather indirect way.

REFERENCES

[1] Hermens, H.J., Boon, K.L., Zilvold, G., (1984): The clinical use of surface EMG, Electromyogr. clin. Neurophysiol., 24, pp. 243-265.
[2] Bajd, T., Vodovnik, L., (1984) : Pendulum testing of spasticity, J.Biomed. Eng., Vol. 6, no. 1, pp. 9-16.
[3] Burke, D., Andrews, C.J., Gillies, J.D., (1971): The reflex response to sinusoidal stretching in spastic man, Brain, vol. 94, pp. 455-470.
[4] McLellan D.L., (1977): Co-contraction and stretch reflexes in spasticity during treatment with baclofen, J. Neurol. Neurosurg. and Psych., Vol. 40, pp. 30-38.
[5] Postema, K., (1983): Spastische parese bij infantiele encephalopathie. Een onderzoek naar klinische en electromyografische kenmerken en de invloed van dantroleen natrium. Academisch proefschrift, Vrije Universiteit, Amsterdam.