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EMG Reaction in Muscles about the Knee to passive Velocity, Acceleration and Jerk Manipulations

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Abstract--**Twenty subjects, 10 adults and ten children were tested in this study. Each test consisted of applying an ensemble of velocities to the lower limb using a torque motor in such a way that the entire range of motion of the knee was traversed. Eight velocities between 60 deg/sec and 280 deg/sec were reached at 2-3 different acceleration rates and 1-2 different rates of jerk. EMG from three muscles, vastus, rectus, and hamstring were recorded during each move. Regression and correlation coefficients between EMG and kinematic parameters indicated different reactions in both muscle groups and age groups to each of the three parameters.**

I. Introduction

In 1999 the authors demonstrated that muscle with spastic cerebral palsy, under general anesthetic, showed no evidence of spasticity but continued to demonstrate differences in biomechanical properties as compared with normal limbs under the same conditions[1]. Our conclusions from this work stated that these differences were due to long term effects of spasticity on muscle tissues. Changes in muscle tissue of those with cerebral palsy have also been demonstrated by other investigators at our institution[6]. It is our conviction, based on this work, that an assessment of spasticity, and the changes caused by clinical intervention, must include the evaluation of both long and short term effects of spasticity.

ln an effort to separate out these two effects, the authors have constructed a device, the Limb Accelerator, which applies an ensemble of movements, in the sagittal plane, about the knee of a subject. This ensemble is of two types: 1)large, full range of motion (ROM) flexion and extensions, and 2)short duration, high torque bursts. Our objective is to measure closed loop reflex reaction to ROM moves and to calculate passive biomechanical parameters from reaction to the high torque bursts.

Many scientific studies have demonstrated the velocity-influenced nature of tonic muscle reflex activation in agreement with the classic definition of spasticity[4],[3],[2]. What is not well know is the reaction to different accelerations and jerks reaching these velocities. In the cases of spasticity, the authors suspect that different "ramp up" conditions might elicit very different reflex reactions. Before this could be tested on disabled subjects, the authors wanted to determine the reaction of normal muscle to stretch under different dynamic/kinematic parameters.

The work to be presented in this paper will be limited to the EMG reactions of the rectus, vastus, and hamstring muscles to an ensemble of ROM moves performed on normal subjects. We believe the ensembles, and thus the work, are unique in our examination of not only velocity of motion but of the second and third derivative of position, the acceleration and jerk.

II. Procedures

A. The Limb Accelerator

In 2001 the authors began a project designed to examine the reaction of muscles about the knee to passive motion of the lower limb. To accomplish this a device was built called the Limb Accelerator. This device utilizes a four bar linkage to move the limb through its normal range of motion. The nature of this device is such that its travel is limited by the geometry of the linkage, thus the device is totally fail safe, it is impossible for the leg to be driven beyond physiological limits.

A schematic of the Limb Accelerator is shown in Fig. 1. The subjects sits on the seat and places his/her foot in the orthosis. The seat can be moved in two dimensions, up/down and forward/backward to align the knee with the axis of the knee encoder. Note: for illustrative purposes the AFO is not in its

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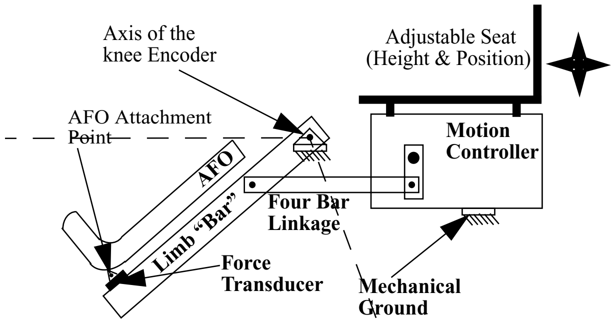


Fig. 1. Schematic of the Limb Accelerator. Seat has two degrees of freedom to align knee axis with knee encoder, four bar linkage limits travel to the angles between the dashed lines. Subject's foot mounts in AFO with breakaway pins at the AFO attachment point.

actual position, in reality it is mounted in front of the "Limb Bar" so that the axis of the knee encoder and the knee are adjacent to each other on one axis. The force transducer is intended to measure force in the plane perpendicular to the axis of the encoder (the sagittal plane of the knee).

The purpose of the Limb Accelerator is to apply accurately defined angular movement profiles to the lower limb about the knee and measure the resultant EMG activation of the muscles. Profiles of position can be constructed which apply velocities, accelerations, and jerks to the limb. For the tests presented here, the Limb Accelerator applied an ensemble of velocities. This ensemble of full ROM flexion and extensions, consisted of eight velocities attained at two to three acceleration rates and one to two rates of jerk.

In a test in which the Limb Accelerator was placed in the center of the Gait Analysis Laboratory and markers were placed on a test subject's ankle, shank, knee, thigh, and hip, the device has proven to be accurate. Limb movements were made with the acceleration device at a number of velocities, accelerations and jerks. Data was recorded with the knee encoder and an eight camera reflective marker gait analysis system. The system can produce velocity profiles which are accurate to within 1.3 deg/sec. over range from 10 to 350 deg/sec.

B. Subject Testing

This study was approved by our IRB committee for the use of human subjects. Each subject gave informed consent and in the case of subjects under age 17, the parent or guardian gave consent in accordance with our IRB regulations.

EMG from three muscles, vastus, rectus, and hamstring, were measured in a total of 20 subjects. Data was fullwave rectified and filtered with a lowpass 6 order butterworth filter at a filtering frequency of 10 hz. The subjects were divided into 2 groups of 10 adults, well over 21 years of age, and 10 children under 17 (mean 11.3 yrs.).

Each subject was given twenty-six limb movements at velocities between 60 and 280 degrees/second. Typically, each velocity was performed four times with different ramp up characteristics for each. These characteristics would consist of one to three different accelerations at one or two different jerks. A set of five measured variables were extracted from position and EMG data of each move. The measured variables were as follows:

1. **Percent of Maximum EMG (Percent_Mx):** This is a comparison between a maximum of the EMG during a voluntary contraction and the maximum EMG response to a movement.
2. **Knee Angle at Maximum EMG (P_Mx):** The difference in degrees between the onset of movement and the knee angle of maximum EMG response.
3. **Percent of Tendon Tap (Percent_Tnd_Tp)**: This is a comparison between the maximum EMG of a tendon tap and the maximum EMG response.
4. **Response time to Maximum EMG (Tm_to_Mx):** The time from onset of movement to maximum EMG response.
5. **Integrated Muscle Response (Imr):** EMG multiplied by time over the entire move.

For all of these variables, the onset of motion is defined as the point where the absolute value of limb acceleration is greater than zero. Some of these variables can be defined graphically as illustrated in Fig. 2.

C. Data Analysis

The above measured values were thought of as the "response" to "stimuli" of velocities, accelerations, and jerks. Regression coefficients and correlation coefficients were calculated for each stimulus and for the combination of stimuli. At first glance, there was an extremely wide variation across the subjects in each group. Attempts to correlate stimulus to

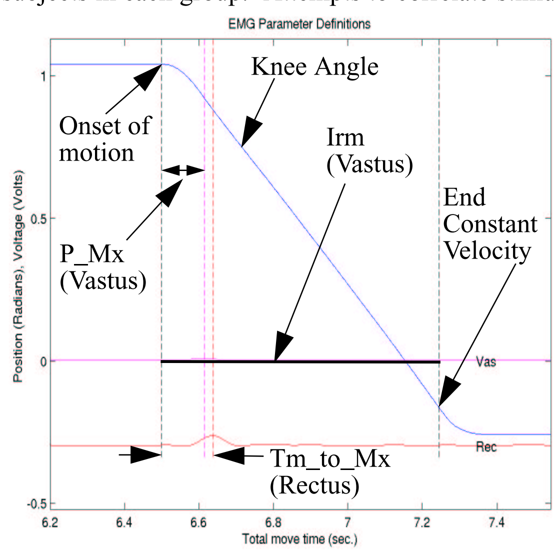


Fig. 2. Graphical definitions of the above EMG parameters. EMG in volts and Position in radians have been scaled to fit the same axis. Note: Limb angle conventions are after Lin & Rymer who defines 0 radians as 90^o knee of flexion[5].

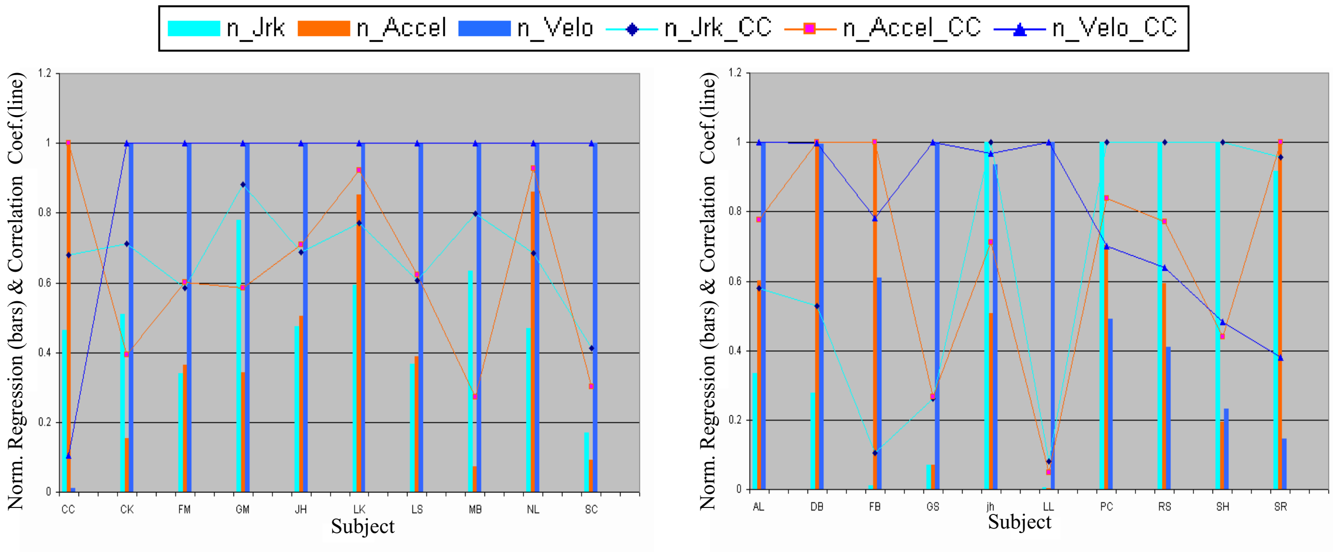


Fig. 3. Adult's Data: Normalized regression coefficients and correlation coefficients between kinematic parameters and P_Mx defined above, all muscles combined.

Fig. 4. Children's Data:. Normalized regression coefficients and correlation coefficients between kinematic parameters and P_Mx defined above, all muscles combined.

response for an entire group resulted in very small numbers. When comparisons were made of data within each subject it became much clearer that there was a correlation between some variables in some subjects. A further step was taken in normalizing all the coefficients on the largest coefficient of each subject. The authors believe this is justifiable because the interest is in how the three stimuli relate to the responses relative to each other. The goal was to show whether or not one or more stimuli cause a greater response than the others.

III. Results

Our initial results indicate two important findings: first, all limbs react to some extent to passive movement, even at the slowest test speeds of 60 deg/sec. Second, the reaction does not solely depend on the velocity of movement. Reactions seen in the EMG data of the three muscles recorded, rectus, vastus, and hamstring, can be linked by regression coefficients to acceleration and jerk. Of even more importance is the differences seen in age and muscle groups.

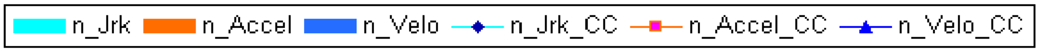
Analysis of the data will begin with a comparison of parameters between adults and children with all muscles combined. The most striking differences in the combined muscle responses are seen in the "P_Mx" measured parameter. In Fig. 3[1] nine adult subjects had a combined muscle response dominated by the velocity kinematic variable. In the case of the children's data (Fig. 4), only four subjects were dominated by velocity. This trend is not unique to a single variable. A similar distribution was seen for the variable "Tm_to_Mx". In this case six adult subjects responded strongest to velocity, while in the children, only four showed a dominant response to velocity.

In addition to differences seen between subject groups, there were significant differences between muscle groups. The parameter P_Mx demonstrates a clear difference between extensor muscles and hamstrings in the adult group. In the hamstrings, P_Mx is dependent on velocity in eight of the ten subjects, while in the extensor muscles of the adults the dependency is distributed across velocity, acceleration, and jerk. If the same variable is examined in the normal children's group, the opposite effect is seen. In this set of subjects, seven extensor muscles are dominated by velocity, while only five of the hamstring muscles have velocity as the dominant parameter.

Differences between muscles, as revealed by other variables, are more pronounced in the younger group than in the adults. For example, the "Tm_to_Mx", response in adults; three extensors and three hamstrings are dominated by the velocity kinematic. In the children, three extensors and five hamstrings are dominated by velocity. If the extensor muscles are separated into the rectus and vastus responses, more obvious differences appear in children between their muscles. Seven of the rectus muscle responses are dominated by jerk or acceleration. In the hamstring muscles, seven responses are dominated by velocity. In the case of the vastus muscles, only four were dominated by jerk or acceleration.

The differences seen in fig. 5 & 6, in children, were the most obvious intramuscular differences observed. The figures show a comparison of the parameter "Percent_Mx" in rectus and hamstring. Seven of the rectus muscle responses are dominated by jerk or acceleration. In the hamstring muscles, seven responses are dominated by velocity. In the case of the

[1] The graphs represent regression coefficients (bars) and correlation coefficients (lines) between the kinematic parameters (jerk, acceleration and velocity) and the measured variables.



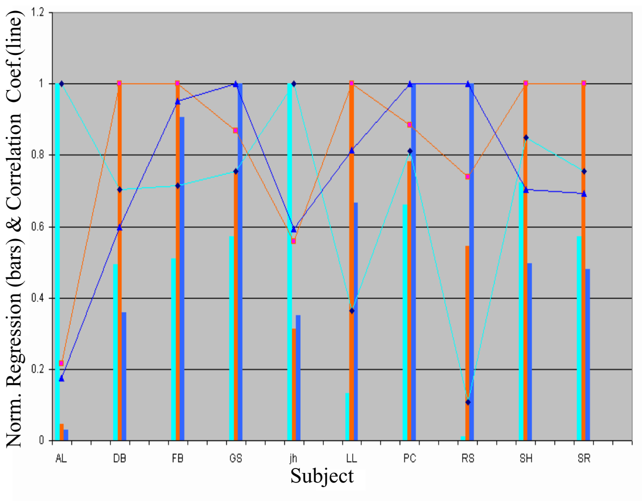


Fig. 5. Children's Data:. Normalized regression coefficients and correlation coefficients between kinematic parameters and Percent_Mx defined above, in the rectus muscle.

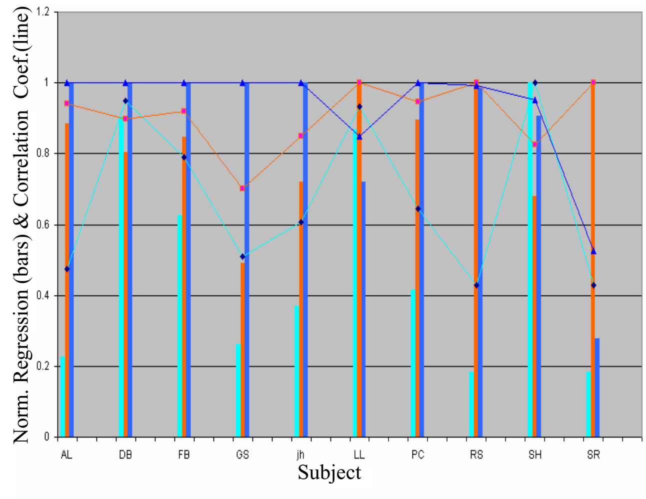


Fig. 6. Children's Data:. Normalized regression coefficients and correlation coefficients between kinematic parameters and Percent_Mx defined above, in the hamstring muscle.

vastus muscles (not shown) only four were dominated by jerk or acceleration.

The only difference between adult muscles was in the "Tm_to_Mx" parameter of the vastus and hamstrings. Six of the vastus muscles show a dominant response to velocity, while only three of the hamstrings demonstrate a similar response.

IV. Conclusions

While the authors recognize that no conclusions can be made based on the small sample size, the data raises interesting questions. Could the differences in responses in adult muscle reflect their role as gravity and anti-gravity muscles? This might make sense, if an anti-gravity muscle were more responsive to acceleration or jerk than velocity, it would be quicker to respond in a situation where the body was landing from a jump.

The differences between adult data and the children's data could suggest that there is a maturation process involved. An interesting test of this would be to recruit subjects in discrete age groups.

The investigations also included a repeated measures test. In this case, one adult was tested on three different days. Each ensemble of velocities were the same, performed in the same order. The results have been a mixture of very consistent, and very different results. In the best example, all three are identical. In the worst example of repeatability two of the three are the same and one is opposite, i.e.. acceleration and jerk dominate where velocity dominated in the first two. The authors do not have an explanation for the differences here. This will be followed up with more rigorous tests of repeatability.

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References

[1] Fee, J. W., Jr. and Miller, F., The Leg Drop Pendulum Test performed under general anesthesia in spastic cerebral palsy, Developmental Medicine & Child Neurology 2004, 46: 273-281.

[2] Fowler, EG, Nwigwe, AI, Ho, TW, (2000), "Sensitivity of the pendulum test for assessing spasticity in persons with cerebral palsy." Devel Med Child Neurol 42:182-89.

[3] Jobin A, Levin MF. Regulation of stretch reflex threshold in elbow flexors in children with cerebral palsy: a new measure of spasticity. Dev Med Child Neurol. 2000 Aug;42(8):531-40.

[4] Lin JP, Brown JK, Walsh EG. Continuum of reflex excitability in hemiplegia: influence of muscle length and muscular transformation after heel-cord lengthening and immobilization on the pathophysiology of spasticity and clonus. Dev Med Child Neurol. 1999 Aug;41(8):534-48.

[5] Lin, C. D., Rymer, W. Z.,(1991) A quantitative analysis of pendular motion of lower leg in spastic human subjects. IEEE Trans. BioMed. Engr. vol 38, no. 9, pp 906-18

[6] Theroux MC, Akins RE, Barone C, Boyce B, Miller F, Dabney KW. "Neuromuscular junctions in cerebral palsy: presence of extrajunctional acetylcholine receptors." Anesthesiology. 2002 Feb;96(2):330-5.