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Surface EMG and Motor Control of the Upper Extremity in Muscular Dystrophy: A Pilot Study

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***Abstract*-**The aims of this pilot study were to determine levels of EMG potentials generated in arm muscles and examine the kinematics of hand motion of subjects with Muscular Dystrophy. A series of tests were designed to record EMG during maximal isometric force application, and to study synergistic muscular activity during arm motion. A test-bed was constructed where the subjects were seated next to a table and were asked to apply maximum radial force with their elbow flexed at 30^o. The force attitude was 30^o, 60^o, 90^o, and 120^o degrees relative to the lateral aspect. For the dynamic tests, targets were placed along the same attitudes and the subjects were asked to reach for the target with a special arm support provision that ensured frictionless sliding. The limited results obtained to date show that the onset/termination of muscle activation could be recognized and activity level could be identified. Synergistic muscle activity and coordination patterns were identifiable in the subjects tested from the residual muscle potentials. Kinematic characteristics identified for point-to-point hand movements resemble those of healthy subjects. These results support further inquiry into the use of electromyography and motion patterns as methods for determining motor control strategies in people with MD.

***Keywords*–**Kinematics, Motor Control, Electromyography, and Muscular Dystrophy

I. INTRODUCTION

Surface EMG (SEMG) has been used to examine changes in the power spectrum during isometric and isotonic contractions to discriminate neurophysiological differences between healthy and MD subjects [1,2]. SEMG has also been employed to examine the affects of progressive resistive training in myotonic MD [3,4]. In disorders such as Parkinson's, Huntington's, Athetosis, Dystonia, Cerebellar Ataxia and Upper Motor Neuron Syndrome EMG recordings were employed to show that the characteristic triphasic agonist-antagonist-agonist EMG burst pattern exists in single joint rapid arm movements [5]. This study seeks to answer the question whether the SEMG is sufficiently intact in MD subjects to facilitate exploration of motor control strategies that these subjects employ using established methods.

Kinematic features of multijoint arm movement have been used in an attempt to understand how the CNS executes control of the movement [6-12]. A thesis for CNS planning and control of the arm kinematics is termed trajectory formation. Trajectory formation is subject to changes in arm posture and the speed of hand movement from initial to final position. While moving the hand between initial and final positions in a plane the hand trajectory is roughly straight and forms a unimodal velocity profile. A ratio of peak velocity to average velocity of 1.88 has been shown to be constant in such movements regardless of changes in the movement amplitude or duration [8]. Moreover, the velocity profile remains unimodal for repetitive movement sequences but the ratio is reduced to 1.57, a range of 1.60-1.90 has been reported [10, 13,14]. This behavior is independent of the location of the initial and final positions in the workspace. However, it should be noted that some investigators argue that arm movement is planned in the joint variables such as angular displacements [15,16].

Based on the thesis that CNS planning occurs in the hand space it can be hypothesized that hand trajectories formation in the presence of neuromuscular pathology affecting muscular function will be planned similarly. That is, a roughly straight hand trajectory and a unimodal velocity profile will be formed in point-to-point arm movements in MD even if biomechanical compensation mechanisms are employed.

II. METHODOLOGY

A. Subjects

Two healthy subjects age 14, 18 and two MD subjects with Becker's type MD (BMD) age 18 and Duchenne's MD (DMD) type age 14, all right handed volunteered to participate in the study. Each subject and/or guardian was informed of the risks and benefits of the research and gave informed consent.

B. Data Acquisition

BioResearch EMG system with a resolution of 0.1μV and a sampling frequency of 3000 Hz were used to monitor muscle activity. The bicep brachii, latissimus dorsi, posterior and anterior deltoids, lateral head of the triceps, brachioradialis, carpi ulnaris flexor, and the carpi ulnaris extensor were monitored. Concurrently, motion of the arm was tracked at 50 Hz with the aid of a Mac-Reflex motion analysis system. Passive reflective markers were placed at the ulnar styloid, humeral epicondyle, acromial process, sternoclavicular joint, manubrium, xyphoid, mid-span of the forearm, upper arm, manubrium and clavicle. The forces produced at the hand during isometric contractions were recorded with a 6 DOF force/torque sensor anchored to the test table using sampling rate of 3000 Hz.

C. Test Protocol

Subjects were seated at a test table and were asked to perform two tests consisting of an isometric and a dynamic task. Both tasks were conducted in the transverse plane without any requirement for elevation of the arm. The subject was positioned at the table with the upper body held erect so that their upper arm hangs vertically and the forearm extended at 90^o. For the isometric task the force transducer was fixed to the table at 30^o, 60^o, 90^o, and 120^o degrees

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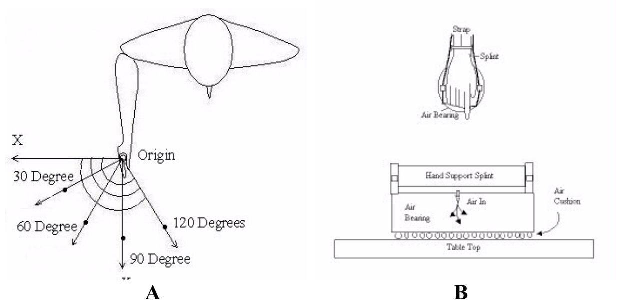


Fig. 1: Initial posture with the body's medial/lateral axis aligned with the X axis of the Cartesian coordinate system fixed in the table. Attitude lines are set from the X -axis at 30^o, 60^o, 90^o, and 120^o degrees (A). The force transducer was placed along these lines for the isometric task. Targets were located at the site the force transducer was set for the isometric task. During the isometric task the forearm segment is supported by the air bearing (B) with the wrist restricted by the splint fixing the air bearing to the forearm .

attitudes. To position the force transducer, the forearm was fully pronated, then the arm extended along the attitude line until 30^o degrees flexion between the forearm and upper arm was reached.

The isometric effort was produced by pushing anteriorly for 5 seconds then pulling posteriorly for 5 seconds with maximal force. Subjects were asked to maintain the isometric force in the anterior/posterior directions as much as possible but were given no feedback as to the actual direction in which the forces were being produced. The dynamic test consisted of moving an air bearing supporting the forearm at the wrist over target positions (Fig. 1A). Each isometric test site and the origin served as both a start position and target position. The wrist joint was constrained by the forearm support, hence forcing the acquisition of the target to be accomplished by shoulder and elbow joint rotations and/or changes in upper body posture (Fig. 1B). Subjects were instructed to conduct the tests at a self-selected pace and to maintain an upright posture as much as possible throughout the movement.

III. RESULTS

A. Data Analysis

Data handling and analysis were performed using Matlab®. EMG data were filtered using a 4th order Butterworth low pass filter at a cutoff frequency of 6 Hz, linear enveloped and then normalized to the maximum value. Force data were calibrated and superimposed with the corresponding SEMG. Tangential velocities were obtained from the hand coordinates (x, y), which were smoothed using a 2nd, order Butterworth filter at a cutoff of 12 Hz before being differentiated.

B. Isometric SEMG

The synergistic actions of the upper extremity musculature in the healthy subjects were clearly demarcated in the SEMG pattern during the isometric task. Moreover, similar synergistic muscle activity patterns were maintained by these subjects at the various positions tested as illustrated in Fig. 2A. These results simply confirm that during isometric pushing/pulling actions the level of EMG potential generated increases with the force [17].

Synergistic muscular activity produced by the DMD subject is not as easily discriminated. The complexity of synergistic muscle coordination generated by this subject in order to produce a maximal isometric effort is shown in Fig. 2B. The figure also demonstrates that while producing a maximal effort a muscle's role as a flexor or an extensor is not as clearly discernable as in the healthy subject. Yet, the initiation and termination of the isometric effort is evident within the SEMG in the MD subjects tested even though all available muscles may be contributing throughout the effort. Peak EMG potentials generated during the isometric and dynamic tests are presented in Table 1.

B. Isometric Force

The level of force the subjects with MD produced was reduced 30 to 80 percent of the force levels that the healthy subjects were capable of producing (Fig. 2). These results are similar to those reported in the literature experienced in manual muscle testing methods [18]. Generally, the maximum force level developed by these MD subjects was produced while attempting to extend the arm by pushing on the force transducer. Even with a reduction in force level the subjects were capable of maintaining a constant level of isometric force for short durations. This result is counter to what was anticipated based on the fact that flexor muscles have a tendency to be stronger than extensor muscles in MD.

C. Dynamic Task

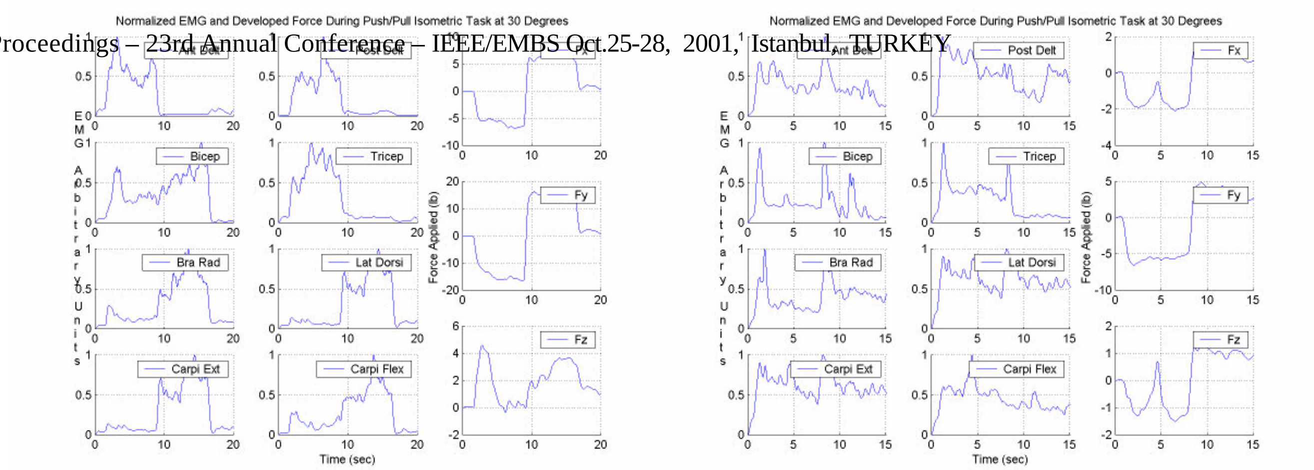
The features for the arm motion of the healthy 14 y.o. and 18 y.o. subjects were within reported limits[6-10]. Hand paths, displacements, and tangential velocities are plotted in Fig. 3 for a start positions at the origin for the age matched healthy and DMD subject. The majority of the trajectories produced by all the subjects were straight point-to-point trajectories as in Fig. 3. However, for some of the movements the MD subjects were not capable of acquiring the target in a single smooth motion. That is, they lack the functional ability to produce a smooth movement, which causes in attitude changes throughout the path to be formed within the movement.

Both the healthy subjects had a mean V_{peak}/V_{mean} ratio that falls in the reported range of 1.60-1.90 [10, 13-15], as does the BMD subject however, in the DMD subject this ratio increased to a mean ratio of 2.35. The peak velocity to different targets from the same initial position can vary even though the peak velocity to and from the target remains roughly equivalent. Subjects produced more or less the same peak velocity throughout the activity when they acquired targets from the origin as in Fig. 3.

The velocity profiles of the healthy subjects are unimodal

Table 1
Peak EMG potentials produced during testing.

Subject	Isometric	Dynamic
Healthy 18 yo	300 µV	100 µV
Healthy 14 yo	250 µV	100 µV
BMD	150 µV	40 µV
DMD	50 µV	---



A: Healthy Subject **B: DMD Subject**

Fig. 2: SEMG potentials and forces produced by healthy and age matched Duchenne's MD while executing the isometric push/pull task along the 30° degree attitude. Subjects were instructed to produce a maximal isometric effort in the an terior/posterior (Y) direction by first pushing anteriorly then posteriorly for 5 seconds respectively. The SEMG potentials of individual muscles are normalize to their maximum value for the given effort.

for most of the point-to-point hand movements. A bimodal velocity profile was occasionally generated when the air bearing failed at the edge momentarily introducing a significantly higher friction coefficient. In the MD subjects the inability to maintain functional control over the movement turns out multi-modal velocity profiles in addition to the changes introduced by the momentary sticking described above.

IV. DISCUSSION

Due to the small number of subjects in this study the following discussion should be treated as preliminary and its validity is limited to the subjects tested. In this study the residual motor activity potentials of MD muscles realized with SEMG as obtained under isometric and dynamic conditions were at significant levels (Table 1) [1,4]. Moreover, potentials emerged at sufficient levels for use in studies for the purpose of determining muscle coordination strategies, estimating muscle contribution, and agonist selection at onset of movement [3,6,19,20,21]. For the MD subjects tested the SEMG potential levels generated are reduced as anticipated [2-4] but they are also large enough to suggest when and perhaps how much a muscle is contributing to an effort. This information is key to understanding how the CNS copes with a neuropathology affecting muscle pathology as well as function.

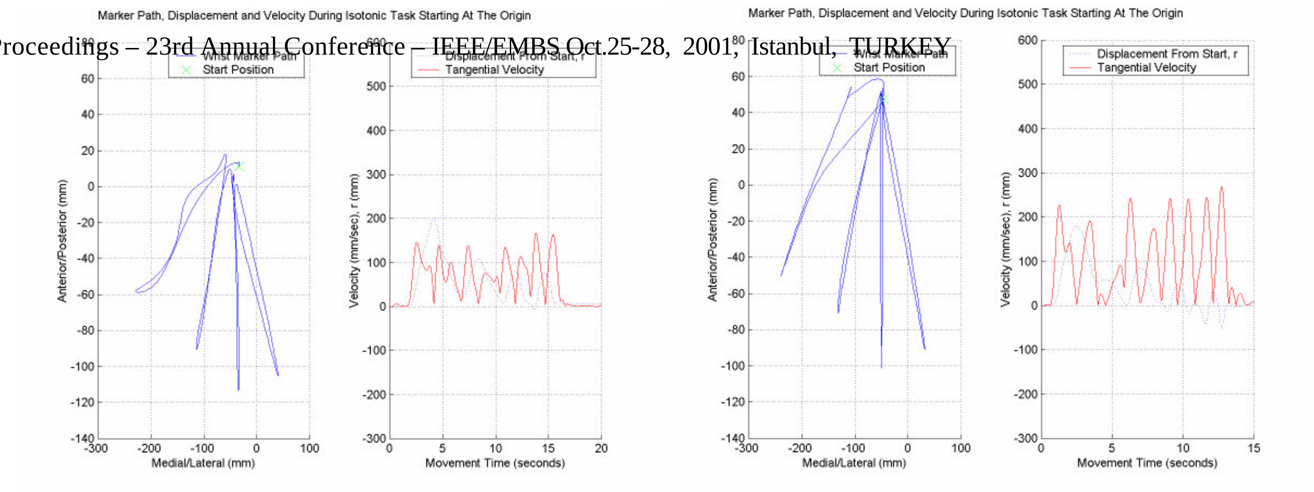
Despite being unaware of the force magnitudes being developed, both the MD and healthy subjects were capable of maintaining relatively consistent levels for the test duration as shown in Fig. 2. This suggests that in MD while the upper extremity may have force-generating capabilities of adequate strength, the isometric force characteristics these individuals produce could mimic the healthy model and should be studied more extensively.

Voluntary integrated muscular activity is necessary to produce an isometric force or a desired motion. Because the force-generating capabilities of the affected MD muscle are reduced the subject must employ adaptive responses. Two possible approaches the CNS could take to achieve this goal are altering muscle mechanics or system dynamics. Adaptation of muscle mechanics may take the form of altering muscle contributions via changes in coordination and/or activity level. This is an impression supported by the isometric test results obtained which suggests that a greater amount of co-contractive muscle activity is necessary to produce the desired action.

Breakdown in the ability to maintain a straight smooth hand trajectory while executing a movement could be a measure of functional ability. Namely, the greater the number of trajectory changes between two points indicates a greater decline in ability. However, even though upper body motion was allowed and large in amplitude at times in the MD subjects the hand paths produced were predominantly straight. This suggests that the compensation mechanisms are employed in such a manner as to not only assist the movement but also to constrain hand motion along roughly straight trajectories. In other words as long as viable compensation mechanisms can be affectively employed to produce a desired point-to-point hand movement the trajectory shall remain relatively straight. Changing the position of a joint relative to the hands initial position can alter the system dynamics as well as changing the force-generating requirement placed upon the individual muscles Due to muscle skeletal mechanics and the fact the arm orientation affects system dynamics the initial and final position of the hand in the work space has an affect on the individual's ability to maintain functional control over arm motion.

V. CONCLUSION

Researchers have used EMG, kinematics, and dynamics of the upper extremity in research paradigms towards eliciting principles of motor control [5,7-16, 19-22]. This work examined some of these parameters in the upper extremity of two healthy and two MD subjects. The intent was to establish potential levels generated with SEMG and to investigate kinematics of the hand trajectories in the workspace. The preliminary results support the feasibility of these methods to further explore muscle coordination and motor control strategies in MD. Based on the thesis that indeed CNS planning occurs in the hand coordinates to



A: Healthy Subject **B: DMD Subject**

Fig. 3: Hand path was developed from the origin to the target along the 30 °degree attitude then return to the origin, repeated until each target was acquired. The velocity and displacement from the initial pos ition is also presented for the entire movement task.

produce straight trajectories, then adaptations made to preserve trajectory may be determined. Moreover, such work could provide insight into the hierarchy of CNS motor control, i.e. is the motion planning in the joint coordinate or in the hand coordinates as postulated here.

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