A summary of the work done on AN EMG-DRIVEN VIRTUAL ARM FOR STUDYING NORMAL AND PATHOLOGICAL MOVEMENTS

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**SUMMARY**

Studying human movement is complicated by the highly integrated nature of the neuromuscular system. Control of even simple tasks requires the coordinated action of redundant muscles and continual feedback from afferent pathways. We have developed and tested an EMG-driven Virtual Arm to better understand normal and pathological movements. The Virtual Arm moves in “real-time” in response to elbow flexor and extensor forces developed by the subject. Because the model predicts individual muscle forces it is possible to study how poorly timed muscle activation patterns affects the resulting movement. Further, the Virtual Arm may be a useful tool for designing rehabilitation protocols. For example, muscle re-education following stroke might benefit by practicing arm movements in a virtual environment. In this way the patient does not have to overcome the weight of their arm nor are they affected by sensitive stretch reflexes since their actual arm never moves. The Virtual Arm can simulate both isometric and slow dynamic movements as described in this paper.

**INTRODUCTION**

Human movement requires the coordinated action of an over-determined musculoskeletal system. With few exceptions there are more muscles than needed to move a joint through its range of motion. This redundancy and the integrated nature of our motor system present challenges to those studying motor control, and complicates rehabilitation following neurologic injury. In a previous series of experiments we developed and tested an EMG-driven Virtual Arm to investigate how individual muscles and/or groups of muscles are activated to produce isometric elbow joint moments [1]. Joint moments were used to control elbow movement of a 3-dimensional graphical model of the arm. That is, although the subject’s arm remained fixed during testing, a virtual arm displayed on a computer screen moved in real-time as the subject generated isometric flexion and extension efforts. In this paper we expand on our previous work by incorporating quasi-dynamic movements and variable external loading to our “real-time” EMG-driven Virtual Arm. Experimental data for a healthy subject are presented and we discuss how training in a virtual environment may benefit stroke survivors and other patients with motor deficits.

**METHODS**

The Virtual Arm is a 3D graphical model of a human torso, arm and hand incorporating the major elbow flexor and extensor muscles. Elbow flexion and extension of the Virtual Arm is controlled by muscle forces developed by the biceps (long & short heads), brachialis, brachioradialis, and the 3 heads of the triceps. Muscle forces are predicted using an EMG-driven Hill-type model using experimentally recorded subject specific electromyograms (EMGs). Optimal fiber and tendon slack lengths for each muscle are determined using a “Tuning” process described elsewhere [2]. Briefly, model-tuning is achieved by having the subject generate time-varying isometric elbow flexion and extension efforts in addition to slow dynamic movements against an external load. A dynamometer (Biodex Inc.) is used for these trials recording angular position, velocity and torque and synchronized with the EMG data. A stochastic optimization algorithm is then applied with the objective of minimizing the sum squared differences between the external moment recorded by the dynamometer and the moment computed by the EMG-driven model. Once tuned, the Virtual Arm can predict individual muscle forces from newly sampled EMGs and joint positions. Muscle lengths and moment arms are determined at each time step based on the current elbow angle. Muscle forces developed by the subject are dependent on the external load which is simulated by altering the mass of a hand-held virtual ball (Figure 1). The size of the ball is proportional to its mass providing the subject with a visual representation of the load they are attempting to control. The Virtual Arm responds in “real-time” to forces developed by the subject. In this manner the subject can modify their muscle activations to produce the desired elbow trajectory or attain a prescribed fixed joint angle.

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**Figure 1.** The subject is holding a 7 Kg. weight at a fixed elbow angle. Developing too much force will cause the Virtual Arm to flex while not enough force will cause the arm to extend.
RESULTS AND DISCUSSION

The tuning-process converged to a set of muscle parameters resulting in a good fit between the torque recorded by the Biodex and the subject’s isometric moment (R² = 0.89, data not shown), and the moment when slowly moving (30°/s) a hand-held weight of 7 kilograms (Figure 2, R²=0.90). The importance of model tuning is clearly illustrated when comparing the “Pre-Tuned” and “Tuned” Virtual Arm data relative to the torque measured by the Biodex. Once tuned the model was exposed to a new set of muscle activations recorded while the subject flexed and extended the arm (Figure 3). The EMG-driven model successfully predicted the net elbow moment (it was not re-tuned) from subject specific EMGs and the model-predicted muscle forces. An advantage of computing individual muscle forces is that it is possible to partition the net moment into agonist & antagonist components (see Figure 3). An increase in extensor force when the flexion moment was greatest may seem counter-intuitive however it is consistent with the functional need for joint stabilization. As seen in Figure 3, the subject did not grossly co-contract to stabilize the joint, but rather a well-coordinated spatio-temporal pattern seems to have been used.

For example, stretch reflex thresholds differ for elbow flexors and extensors and vary with muscle length [3]. Thus, the amount of co-activation at the elbow changes not only with level of effort (e.g., increasing external load) but also with changes in joint angle. Training a patient to move a Virtual Arm while the paretic limb remains fixed minimizes the confounding effects of stretch reflex while allowing the patient to focus on task specific muscle activation and timing patterns.

Developing novel therapies to improve outcomes is complicated by the inter-dependent nature of motor deficits secondary to stroke. Motor re-learning in a virtual environment, as is possible with our Virtual Arm, may provide a mechanism for uncoupling these dependencies. This is an important consideration given the limited window of opportunity that exists during acute rehabilitation.

CONCLUSIONS

The EMG-driven Virtual Arm can predict muscle forces and elbow movements in ‘real-time’. The ability to simulate movement in a virtual environment may be an effective rehabilitation tool for those with neurologic injury.

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REFERENCES