DETERIORATION OF KINEMATIC AND MUSCLE PERFORMANCE AND ASSOCIATED CORTICAL ACTIVITY RELATED TO INCREASED SHOULDER ABDUCTION DRIVE IN CHRONIC HEMIPARETIC STROKE

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INTRODUCTION

A very important cause of upper-extremity motor disability following chronic hemiparetic stroke is abnormal joint coordination between the shoulder and elbow. Abnormal movement patterns caused by this discoordination, described by Brunnstrom (Brunnstrom 1970) as flexion and extension synergies, involve the coupling of elbow and shoulder movements, thus severely limiting the ability to make functional movements such as reaching. Previous static (Dewald and Beer 2001) and dynamic (Beer et al. 1999; Sukal et al. 2007) studies have shown that independent torque generation, arm workspace and reaching ability can all be seriously affected when stroke survivors increase the amount of shoulder abduction drive needed to lift the arm against gravity.

To investigate the neural mechanisms behind the appearance of abnormal coordination patterns during post-stroke recovery, we used an experimental setup consisting of a high-density electroencephalogram system (EEG), an electromyographic (EMG) system and a robotic device. This study experimentally and quantitatively investigates peripheral performance measures such as muscle and kinematic activity simultaneously with cortical activity. Our results provide evidence for a deterioration of elbow/shoulder kinematic and muscle coactivation variables combined with changes in cortical activity during realistic upper-extremity reaching movements when increasing shoulder abduction torques.

METHODS AND PROCEDURES

Eight able-bodied subjects (51-62 years old, all with right hand dominance) and 10 chronic hemiparetic stroke subjects (52-69 years old, all with subcortical white matter lesions) participated in our study. The experimental setup included EMG, EEG, and a robotic system known as the Arm Coordination Training 3D (ACT^{3D}) system.

Surface EMG signals were recorded from 12 muscles of the arm and trunk on the dominant limb side of control subjects or the paretic limb of stroke subjects. Scalp recordings were made with a 160-channel Biosemi EEG system.

Three different reaching tasks were performed in the horizontal plane with different required levels of shoulder abduction drive, in order to deal with different gravitational loads while reaching. The three reaching tasks consisted of making a ballistic reaching movement to a visual display target while supported by a haptic planar surface (abbreviated as TbRe), while supported in free space by a constant force equal to the weight of the arm (0Re), or while having to lift 25% of their maximum abduction force (25Re). 120 trials were performed for each task.

Quantitative indices were developed using a biomechanics-based method that represents muscle activations as 3D vectors in joint torque space (Yao et al. 2006). Indices included a Muscle Selectivity (MS) Index, which quantifies muscle coactivation (a higher MS indicates higher coactivation), and an Effective Torque Contribution (ETC) Index, which quantifies muscle contributions to torque generation in the expected directions (a higher ETC indicates expected behavior).

RESULTS AND DISCUSSION

Stroke subjects demonstrated muscle activity consistent with movement synergy patterns during the motor tasks, as well as significant decreases in kinematic performance, as shoulder abduction drive was increased. As deltoid activity increased to abduct the paretic arm, elbow extensor activity decreased and elbow flexor activity increased as part of the flexion synergy. Both shoulder and elbow joint excursions and velocities decreased significantly between the TbRe and 25Re tasks by about 40-60% ($p<0.005$).

The MS and ETC indices also clearly indicated differences between stroke and control subjects in performance of the tasks. The TbRe task did not produce significant differences between control and stroke subjects. However, the 0Re task showed significantly lower ETC values (30%, $p<0.05$) for stroke subjects during the movement, suggesting that paretic limb muscles were contributing to torques in unexpected directions. For the 25Re task, MS values for stroke subjects were significantly higher after 20 ms after movement onset (75%, $p<0.05$). Overall, control subjects showed a decreasing trend in MS as the gravitational load was increased, while stroke subjects showed an increasing trend. This increasing trend suggested that control subjects were able to coactivate more muscles to deal with lifting and reaching (low MS), while stroke subjects were unable to reach while lifting (high MS).

Accompanying these peripheral changes, it was found that stroke subjects began to use more of the ipsilateral, or contralesional, hemisphere when they increased the amount of shoulder abduction drive. Furthermore, more heavily impaired stroke subjects (as determined by Fugl-Meyer Assessment scores) exhibited more ipsilateral cortical activity than lesser impaired subjects.

SUMMARY

Our results show differences between control and stroke subjects in quantitative peripheral performance of motor tasks and for corresponding differences in brain activity. This provides insight into the underlying mechanisms behind abnormal joint coordination following stroke. More specifically, results suggest that increases in abnormal discoordination are linked with the increased use of contralesional areas and their projections, which may include bilateral ventromedial bulbospinal pathways.

REFERENCES

Beer, R., et al. (1999). Prog Brain Res **123**: 455-60.

Brunnstrom, S. (1970). Movement therapy in hemiplegia : a neurophysiological approach. New York, Harper & Row.

Dewald, J. P. and R. F. Beer (2001). Muscle Nerve **24**(2): 273-83.

Sukal, T. M., et al. (2007). Exp Brain Res **183**(2): 215-23.

Ward, N. S. (2004). Curr Opin Neurol **17**(6): 725-30.

Yao, J., et al. (2006). J Biomech **39**(8): 1527-30.

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