fMRI BRAIN IMAGING DURING SIX DOF MECHANICAL MEASUREMENTS OF UPPER LIMB ISOMETRIC CONTRACTIONS

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INTRODUCTION

A six degree of freedom (DOF) load cell technology is used to measure joint torques in a functional magnetic resonance imaging (fMRI) environment in an unprecedented manner. This system offers substantial improvement over existing methods that monitor at most one DOF during fMRI motor experiments. Developing a functional brain map depends on adequate characterization of motor output. Collecting multiple joint torques and fMRI simultaneously surpasses all current methods used to assign brain areas to motor functions.

METHODS

A novel system using a non-ferrous six degrees of freedom load cell (JR3, Inc., Woodland, CA) to monitor shoulder and elbow joint torques is developed to conduct functional MRI investigations of the human motor cortices (Figure 1). The subject's arm is surrounded by a fiberglass cast to prevent wrist movement and insure proper joint position [1]. A combination of delrin and garolyte provides an interface

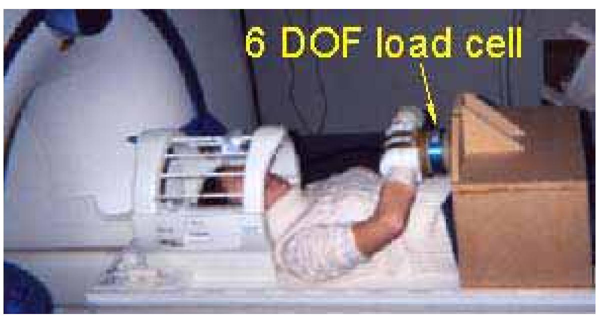

Figure 1: Subject position and load cell mounting setup used during function MRI sessions.

surface to evenly distribute the loads generated by the subject across the entire load cell surface. A wooden frame holds the load cell in position. Load cell signals are filtered using 8^{th} order low-pass Butterworth filters with a cutoff of 15-Hz and 4^{th} order elliptical filters with a sharp 10-Hz cutoff. The filters remove artifacts caused by the gradients and radio frequency signals used in the functional MRI sequence. This system preserves the force and torque information used to calculate joint torques during contractions of the upper limb and provides feedback to the subject. Using a TTL pulse from the MRI system, joint torque samples are synchronized with the MRI recordings.

Functional MR images are collected from a 3.0-Tesla MR scanner (Siemens Trio, 3T) using a 2D gradient echo, echo-planar imaging sequence (TR=2000ms, TE=30ms, FA=80°, voxel=3.4x3.4x3mm^3, 31-slices, 64x64 matrix). Following the functional imaging an anatomical scan of the entire brain is acquired as a reference image for functional data using an MP-RAGE T1 weighted 3D gradient echo sequence (TR=2100ms, TE=4.38ms, FA=8°, voxel=1.0x1.0x1.0mm^3). Visual stimuli for the functional MRI paradigms are observed through an MR compatible mirror mounted on the head coil aimed at a rear-projection screen fitted in the magnet. An event-related protocol using short, low-effort contractions with approximately 30-seconds between tasks is designed to minimize head movement artifacts during analysis [2].

RESULTS AND DISCUSSION

The technique is verified both with a phantom MRI study and an incremental mass study. No artifact is caused by the presence of the load cell on phantom images. Load cell recordings inside the magnet match load cell recordings outside the magnet for the same masses. A study of shoulder and elbow activation in the motor cortices during elbow flexion and shoulder abduction confirms the feasibility of this measurement technique. An isolated joint torque is difficult to produce voluntarily without cocontraction. Substantial secondary torques are observed while monitoring multiple isometric joint torques during tasks such as elbow flexion and shoulder abduction. Thus, functional activity on the motor cortex may be related in large part to these secondary joint torques. For example, shoulder flexion is prominent during elbow flexion tasks and therefore, accounts for some portion of the neural activity.

CONCLUSIONS

This methodology offers a unique and novel approach to investigate cortical control of the upper limb. It permits a greater association of cortical activity with the multi DOF nature of motor output. The system records multiple isometric joint torques generated by a subject and enables detailed study of the relationship between elbow/shoulder torques and associated cortical activation sites. To date, neuroimaging motor studies incorrectly associate most observed neural activity with a single motor output measurement consequently not accounting for unmonitored motor events. Assigning cortical regions based on a single DOF measurement grossly undermines the complexity of human movement. By incorporating multiple elbow/shoulder torques, we can better characterize the cortical activation map in both healthy and neurologically impaired subjects.

REFERENCES

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