An fMRI-Compatible Haptic Force Feedback Device for Virtual Reality Experiments

L. Di Diodato[1], R. Mraz[2], C. Nangini[1], N. Baker[2], S. J. Graham[1,2]

[1]Department of Medical Biophysics, University of Toronto, Toronto, ON, Canada, [2]Sunnybrook and Women's College Health Sciences Centre, Toronto, ON, Canada

Introduction

Simulation of ecologically valid (real-world) behavioural tasks and environments using virtual reality (VR) technology is becoming popular in neuroscience research. Integration with functional magnetic resonance imaging (fMRI) to measure the associated brain activity is desirable, but difficult due to the confined and highly magnetic environment imposed by the imaging equipment. Careful development of fMRI-compatible VR devices is required. For brain activity in VR to be representative of the real-world equivalent situation, the virtual environment must provide extremely realistic sensory feedback. With this goal in mind, a device for use with an fMRI-compatible data glove has been developed that provides forces in one degree of freedom (1DOF) to the fingertip to simulate contact with solid surfaces. The device is validated through illustrative fMRI experiments.

Materials and Methods

The device is illustrated in Figure 1a). The mechanism for providing force feedback is a length of string, in which tension is created by the opposing forces of a motorized spool at one end and a fingertip at the other. The motor is piezoelectric (Elliptec Resonant Actuator AG, Dortmund GER) and consists of a stator (i) and rotor (ii). When the device is turned on, the stator vibrates, exerting a small dynamic force to turn the rotor and spool the string. This force is small enough to keep the string taut while allowing relatively unimpeded motion of the fingertip, thus representing motion in free space. In the off condition, the stator is preloaded onto the rotor with a much greater frictional force, acting as a brake for the spool. As a result, motion of the fingertip is hindered by increased string tension. Turning off the device, therefore, provides the illusion of object contact.

The forces applied by the device were measured using a spring scale in place of a finger to oppose the motor's motion. For both the on and off conditions, values were recorded for maximum static friction, Fs, (exerted when the motor is pushed from stationary to slip mode) and kinetic friction, Fk, (exerted when the motor remains in a constant state of slip).

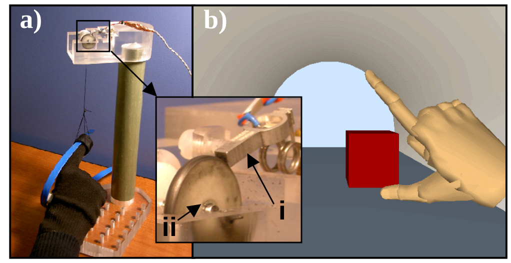

Figure 1: a) Actual and b) virtual representations of the force feedback experiment

To determine fMRI compatibility of the device, phantom images were obtained using a spiral in/out BOLD fMRI sequence (GE 3T/94 Signa System, VH3/M4 software, Waukesha WI) with TE/TR/ϕ = 30ms/2000ms/70^o. SNR and SFNR [1] values were calculated and compared for the cases when a) no device was present in the imaging environment, b) the device was present but off, c) the device was turned on and d) the device was alternately turned on and off in 20-sec blocks.

Finally, the device was employed in a preliminary VR-fMRI experiment, in which six young, healthy adults were visually presented with the virtual environment shown in Figure 1b) and asked to tap a virtual block. Functional MRI-compatible goggles (Avotec, Jensen Beach FL) were used to provide the visual stimulus. Shape Tape™ was used both to translate subjects' hand motion into virtual hand motion and to record finger flexion and extension [2]. The block design for this experiment consisted of 20-sec periods where force feedback was alternately provided and then not provided to support contact between the virtual finger and the virtual block. Subjects were asked to use their finger to determine the location of the virtual block's surface throughout. Activation images were obtained using AFNI freeware [3] via correlation with a standardized hemodynamic response function, convolved with the task design.

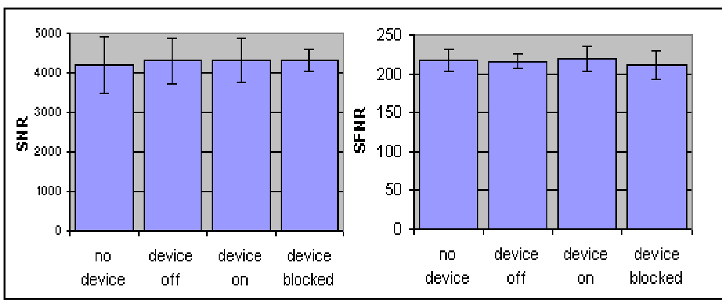

Figure 2: fMRI compatibility.

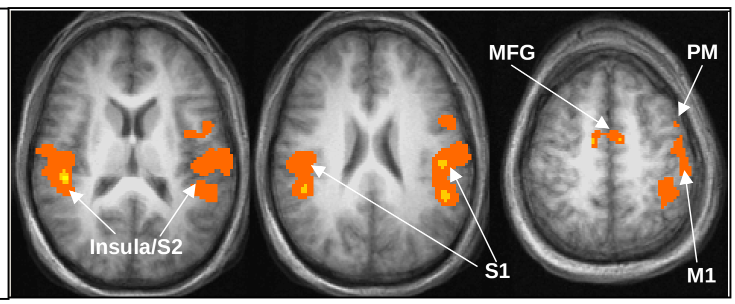

Figure 3: Group fMRI activation images (p<0.01) of force feedback vs. no force feedback for touching the surface of the virtual block.

Results

In the on condition, the device applied forces of Fs=0.6±0.1N and Fk=0.4±0.1N. When the device was turned off, frictional forces of Fs=2.7±0.9N and Fk=2.4±0.6N were presented. These forces are sufficient for supporting motion in free space and object contact, respectively. Average image SNR and SFNR values for the various device and no device cases are displayed in Figure 2. Student's t test results showed no significant difference between these values, verifying that the device is fully fMRI-compatible. Figure 3 shows the group fMRI results obtained during the VR experiment. When force feedback is provided to support object contact, greater bilateral activation is seen in primary and secondary somatosensory regions (S1 and S2, respectively), as well as in the insula and the medial frontal gyrus (MFG). Activity is also increased in the left premotor (PM) and primary motor (M1) cortices. These activation changes presumably reflect increased attention to the task, as well as processing of additional, multimodal sensory feedback to augment task performance. Finger flexion was not measured relative to the position of the virtual block. A difference in task performance could not, therefore, be additionally confirmed with this data. In the future, coordinates of virtual fingertip position will be recorded such that the accuracy with which subjects locate the surface of the virtual block with force feedback can be compared to the case of visual feedback alone.

Conclusions

A device has been presented that supports contact with virtual objects by virtue of 1DOF force feedback. The device exerts forces that are suitable for representing both free space and modest contact with a solid object, with complete fMRI compatibility. Experiments revealed that when virtual objects are touched with force feedback, increased brain activity is observed in somatosensory and motor regions. From a basic neuroscience perspective, such a device can assist in developing understanding of the brain activity associated with use of VR that incorporates data gloves. Numerous other applications are possible, such as evaluation of haptic VR simulators that mimic the biomechanical properties of tissues.

References

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