MR Compatible ERF-based Robotic Device for Hand Rehabilitation after Stroke

A. Khanicheh[1], A. Muto[1], C. Triantafyllou[2], L. G. Astrakas[3], C. Mavroidis[1], A. A. Tzika[2,3]

[1]Mechanical and Industrial Engineering, Northeastern University, Boston, MA, United States, [2]Athinoula A. Martinos Center for Biomedical Imaging, Harvard Medical School, Boston, MA, United States, [3]NMR Surgical Laboratory Massachusetts General Hospital, Harvard Medical School, Boston, MA, United States

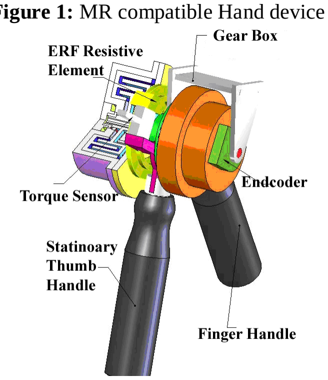
Introduction

Stroke is one of the main causes of morbidity and invalidity in United States. About 80–90% of stroke survivors exhibit motor weakness, and 40-50% experience sensory dysfunction (1). Post-stroke care continues to be advanced to reduce long term disability (2). Initial clinical studies of robotic therapy suggest the additional therapy provided by a robotic device can improve motor recovery (3). Unfortunately, objective evaluation of the specific effects of rehabilitation is technically challenging (4), as too little known regarding the events of post-stroke functional recovery. The goal of our research is to combine functional Magnetic Resonance (MR) methods, with MR compatible robotic devices for rehabilitation to provide accurate, sensitive and specific information into the effectiveness of rehabilitation therapy beyond traditional paradigms. To achieve this goal robotic or mechatronic devices need to be introduced into an MR scanner. The common standard mechanical parts can not be used in MR environment and MR compatibility has been a tough hurdle for device developers. The purpose of the present study was to design a hand devise that employs a non magnetic type of actuation and test it in the MR environment for its MR compatibility.

Materials and Methods

A novel computer controlled, variable resistance hand device was built that employs a non conventional type of actuation, via electro rheological fluids (ERF) which can change their viscosity in response to electric field, shown in Figure 1. A gear box is used to increase the resistive torque coming from ERF element. The handles are the haptic interface for the operator. They were designed to rotate 45 degrees about the center axis and were balanced at the center of mass. One optical encoder and one rotary torque sensor was attached to the ERF resistive element's shaft to measure the patient induced motion and torque, respectively. To evaluate the effects of the magnetic field on the ERF, and to ensure that the introduction of the ERF device in the magnet did not degradate the MR images; and to visualize the possible artifacts caused by the introduction of ERF's in the magnetic field the device was placed in zones 2, 3 and 4 of a 3-T MR system. The currents and voltages were recorded, and three different types of images were acquired: a) Sagittal T1-Weighted Localizer (TR/TE = 2530/3.39 ms; Flip Angle = 7 degrees); b) T1 EPI images (TR/TE = 8000/30 ms) TE = 30 ms); and c) Gradient echo EPI images (TR/TE = 2000/30 ms, Flip Angle = 90 degrees). Zone 4 is the area where the patient's hand will be located when performing the rehabilitation exercises. The imaging object was a cylindrical phantom and the control image was taken without the ERF device. The images were acquired with and without ERF actuated. The signal to noise ratio (SNR) was calculated according to Firbank et al (5) in order to evaluate the noise and to see whether the introduction of ERF's in the magnet filed have affected the SNR of MR images.

Figure 1: MR compatible Hand device



Results

Figure 2 shows the plot of current versus voltage for the actuated ERF inside the MR environment for zone 2 experiments (closed symbols) and outside the MR environment (open symbols). It can be seen that the performance of ERF has not been affected by the MR environment since upper (power) and lower (current) curves almost overlap. Figure 3 shows representative Sagittal T1-Weighted Localizer images from zone 4 experiments when ERF is actuated at about 2.5 and 4 kV for slice [58/128]. Also, subtraction of the control image is listed. No image shift was found.

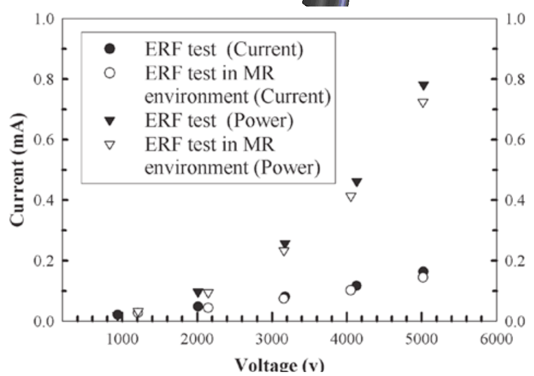


Figure 2: Current and power versus voltage

Table 1. Signal to noise ratio (SNR) of images in zone 4

MP-RAGE [128 slices]	Slice[47/128]		Slice[58/128]		Slice[75/128]	
Voltage (V)	2720	4151	2720	4151	2720	4151
Mean of SNR (ERF device in zone 4)	89.1	87.3	95.7	86.1	89.83	87.4
SD	0.75	0.95	1.8	1.1	0.95	1.2
P-value (between ERF test and control)	0.016	0.005	0.009	0.004	0.02	0.015
Mean of SNR for Control (no ERF device)	92.1		90.5		91.7	
SD	1.3		1.62		1.12	

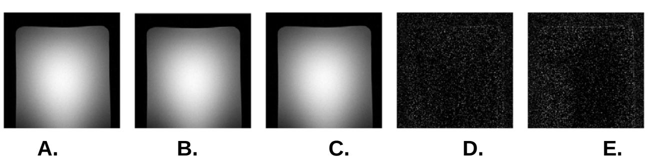


Figure 3: Representative images acquired with the phantom in zone 4: **A**. Control, no ERF in MR environment; **B.** ERF in MR environment activated at 2.5kV; **C.** ERF in MR environment activated at 4kV; **D.** Subtraction of A from B; **E.** Subtraction of A from C.

The signal-to-noise ratio values for Sagittal T1-Weighted Localizer images during the zone 4 experiments were calculated. For the single acquisition technique, four regions were drawn: a large circular region covering most of the test object, and three smaller circular regions placed on the background air pixel. The signal to noise ratio is given by: $SNR = 0.655 \times (S/SD_{air})$, where S is the mean signal intensity in the large circular region, and SD_{air} is the average of standard deviation in the three smaller regions placed over air. Table 1 shows the SNR values for three different slices. The measurements of SNR for six different voltages, gave a mean value of 88.6 (SD=1.42) for the slice 47, 90.2 (SD=1.39) for slice 58, and 88.1 (SD=1.46) for slice 75. Results show that in all cases, the loss of SNR observed was not significant regardless of the ERF being actuated in all zones where experiments were performed since 96% of the data points lie within ± 2 SD.

Discussion

Our novel force-feedback device designed for hand rehabilitation is unique and MR compatible combining very high computer controlled force resistance with compact geometry. Our results demonstrated that the MR environment does not affect the ERF properties. The single acquisition technique showed the ERF device had no degradation in the MR images. The MR compatible hand device may aid in the study of brain after stroke as well as the accuracy, specificity and sensitivity of measurements of motor performance when evaluating rehabilitation. Moreover, it may help in the study about the appropriate maneuvers needed for fMRI of rehabilitation in neurological disorders or stroke. Also, such rehabilitation robotic devices may help to develop a refined MR protocol for optimal neuroimaging of stroke patients, which could become a significant tool in the investigation of stroke pathophysiology.

References

1. Bogousslavsky J, Van Melle G, Regli F. The Lausanne Stroke Registry: analysis of 1,000 consecutive patients with first stroke. Stroke 1988;19:1083-1092.
2. Indredavik B, Slordahl SA, Bakke F, Rokseth R, Haheim LL. Stroke unit treatment. Long-term effects. Stroke 1997;28:1861-1866.
3. Lum P, Reinkensmeyer D, Mahoney R, Rymer WZ, Burgar C. Robotic devices for movement therapy after stroke: current status and challenges to clinical acceptance. Top Stroke Rehabil 2002;8:40-53.
4. Pomeroy VM, Tallis RC. Need to focus research in stroke rehabilitation. Lancet 2000;355:836-837.
5. Firbank MJ, Coulthard A, Harrison RM, Williams ED., Phys Med Biol 1999;44:N261-264