A novel MR-compatible hand induced robotic device in conjunction with fMRI allows accurate brain mapping

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Introduction– Stroke is one of the main causes of morbidity and invalidity in modern society. Approximately 400 persons per 100,000 over the age of 45 years have their first stroke each year in the United States, Europe, and Australia. About 80–90% of stroke survivors exhibit motor weakness [1]. Robot-assisted therapy has been shown to result in significant gains in motor coordination and muscle strength of the exercised shoulder and elbow, sustained in a three-year period following discharge from the hospital [2], and motor fMRI has proven useful in assessing reorganization of cortical mapping in chronic brain patients who underwent an exercise regimen [3]. Here, we present results combining motor fMRI with a novel MR-compatible hand-induced robotic device (MR_CHIROD) [4] to perform accurate brain mapping.

Materials and Methods– For each volunteer, reference (100%) was own maximum force, defined as the force at which subjects could just completely squeeze the MR_CHIROD [group max force: 128 N ± 13 N (n = 6, male)]. All studies were performed on a Siemens Tim Trio (3T). BOLD fMRI was performed using GRAPPA gradient-echo EPI (TR/TE=3000ms/30ms, 1.56 mm×1.56 mm×3 mm). T1-MPRAGE served as anatomical reference. A block design paradigm was used for fMRI. During the action period, subjects squeezed the MR_CHIROD and released continuously. Squeezing rate was guided by a visual 'metronome' cue circle oscillating radially at 0.5 Hz. A fixation cross was projected during rest. Each volunteer performed the paradigm at 45% and 60% of their maximum grip strength and could fully squeeze the device at all levels. The percent levels compensate for performance confounds. Care was taken to minimize elbow flexion and/or reflexive motion, and head motion (typically 0.1 to 0.4 mm as measured by the image registration software). Images were normalized to MNI152 space and smoothed with a 4×(voxel dimension) Gaussian kernel. Significant voxels were $P<0.05$, corrected.

Results– We present results for the volume of activation at the level of the motor area/somatosensory cortex (Table 1). Both the MR_CHIROD and the gel balls resulted in significant increase in activated volume; however, measured activation was larger using the MR_CHIROD. We used the force trace of the MR_CHIROD (Figure 1) as covariate, since it provides exact times that a subject started and stopped squeezing, allowing us to correct for missed strokes etc. Use of the MR_CHIROD force traces as covariates to provide the correct timing information for the task resulted in increased T-scores and activated areas (+147% ± 26%, P=0.0001, paired t-test). The results are visually apparent (Figures 2 and 3).

Table 1. Comparison of gel balls to the MR_CHIROD

Effort level (% maximum))	Gel balls (N=12)	MR_CHIROD (N=6)	*P* values**
45 %	963 ± 702	1976 ± 1272	0.011
60 %	1546 ± 909	2417 ± 1198	0.016
P* values	0.003	0.018	

(*) paired t-test (**) t-test, 1-tailed

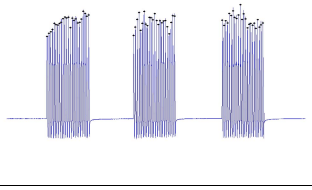
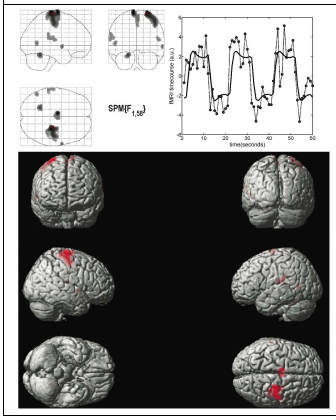


Figure 1: Typical MR_CHIROD force-trace time-series.

Figure 2: Subject activation patterns and timeseries fitting without using the MR_CHIROD force trace as a covariate (left panel) and when using it (right panel). Results shown for two subjects at the 45% level. The increase in activation at the same P-value (P < 0.05, corrected) is apparent.

# of activated voxels in SMC = 1255



# of activated voxels in SMC = 1844

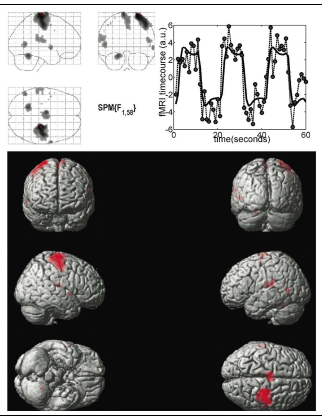
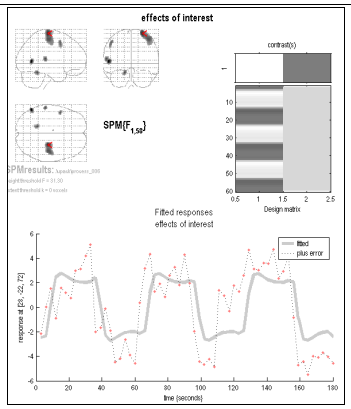
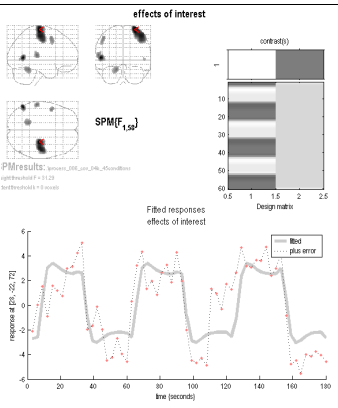


Figure 3: Subject activation patterns and timeseries fitting without using the MR_CHIROD force trace as a covariate (left panel) and when using it (right panel). The increase in activation at the same p-value (P<0.05, corrected) is apparent. This particular subject exhibited non-task activation at the beginning of block 3, which does not correlate with the squeezing trace (shown in Figure 1).





Discussion– Our results show that the number of activated voxels are statistically different only when using the MR_CHIROD and only when the MR_CHIROD force traces are used as covariates. This means that when MR_CHIROD is used and the data are analyzed with performance covariates, the effort that each individual applies is better represented in the brain cortical map, as shown in representative cases. These data suggest that storing performance variables helps to generate more precise brain motor maps, which would aid in the accurate assessment of motor performance in patients after a stroke as well as patients with other neurological deficiencies.

References

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